NASA

Solar Power Satellite
Concept Evaluation

Activities Report
July 1976 to June 1977

Vol. 2 Detailed Report
July 1977

SOLAR POWER SATELLITE

CONCEPT EVALUATION

ACTIVITIES REPORT

JULY 1976 to JUNE 1977

VOLUME I - SUMMARY

VOLUME II - DETAILED REPORT

Lyndon B. Johnson Space Center
Houston, Texas 77058

SOLAR POWER SATELLITE CONCEPT EVALUATION

REPORT OF ACTIVITIES

JULY 1976 to JUNE 1977

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I. INTRODUCTION

Larry E. Bell
Systems Evaluation Off.

Increasing requirements for energy in the United States and the world continue to deplete the fossil fuels at an alarming rate. Projections of the U. S. requirements show an increase in consumption of major proportions (figure I-1).

The conscious efforts by consuming nations to initiate energy policies will slow the rate of increase in consumption, but these efforts do not provide a permanent solution. The energy plan proposed in April 1977 by President Carter is a vital measure for the near term, emphasizing conservation and heavier dependence on coal. For long-term solutions, emphases must be placed on "renewable" or "nondepletable" energy sources such as solar, geothermal, and ocean thermal.

The most promising candidate as a nondepletable energy source appears to be solar power, because of its technical maturity, environmental attractiveness, and abundant availability. Two types of solar power systems to be considered are ground-based and space solar power satellites (SPS). The use of ground-based solar power has the inherent disadvantage of reduced solar radiation (insolation) by the atmosphere, clouds, haze, and nightfall. The use of solar power satellites circumvents this limitation by providing constant power, 24 hours a day, on a near-continous basis.

The Lyndon B. Johnson Space Center report entitled "Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts" (JSC-11568) released in 1976 established the technical feasibility of an SPS program to provide a significant portion of the future electrical demand, starting as early as 1995. Several scenarios of SPS implementation rates were developed, and one (scenario B) was selected as a basis for more detailed evaluation in the period of time documented in this report.

Scenario B proposes an installed capacity of 1120 GW by the year 2025, or about 30 percent of the Federal Power Commission extrapolated projection. The power output on the ground of each SPS is 10 GW, transmitted via two 5-GW microwave subsystems, resulting in a total of 112 satellites in orbit. The construction rate varies from one per year initially (1995) to seven per year during the last 3 years of the 30-year period. The technical feasibility and economic viability of the SPS concept were found to be sufficiently promising to deserve more detailed evaluations.

This report, which concerns effort from June 1976 to June 1977, presents comparative data among various design approaches to thermal engine and photovoltaic SPS concepts, to provide criteria for selecting the most promising systems for more detailed definition. The major areas of the SPS system to be examined include solar cells, microwave power transmission, transportation, structure, rectenna, energy payback, resources, and environmental issues.

The objectives of the SPS activities during this study period were to concentrate on those areas that are major cost factors or of greatest technical uncertainty. These studies include the following:

1. Satellite systems definition: evaluation and selection of preliminary systems definition.

2. Solar cell cost and mass: assessment of the state-of-the-art and projections for cost and mass.

3. Microwave power transmission system: analysis and evaluation of design concepts.

4. Transportation system: definition and costing.

5. Space construction and maintenance: evaluation of structural configurations and the associated manufacturing and assembly concepts.

6. Environmental factors: establishment of space radiation criteria and biological considerations.

7. Natural resources and energy consideration.

8. Program planning and development: description of key ground tests, experiments, early flight projects, and technology advancement.

9. Program costs: costing methodology and systems cost analysis.

This document (volume II) represents the results of this year's efforts by the various technical disciplines in support of the SPS effort. The summarization and conclustions of the effort are presented in Volume I.

POWER GENERATION CAPACITY PROJECTIONS

Source: ERDA 76-141 (discussion draft)
Draft Final Report (Revision A)

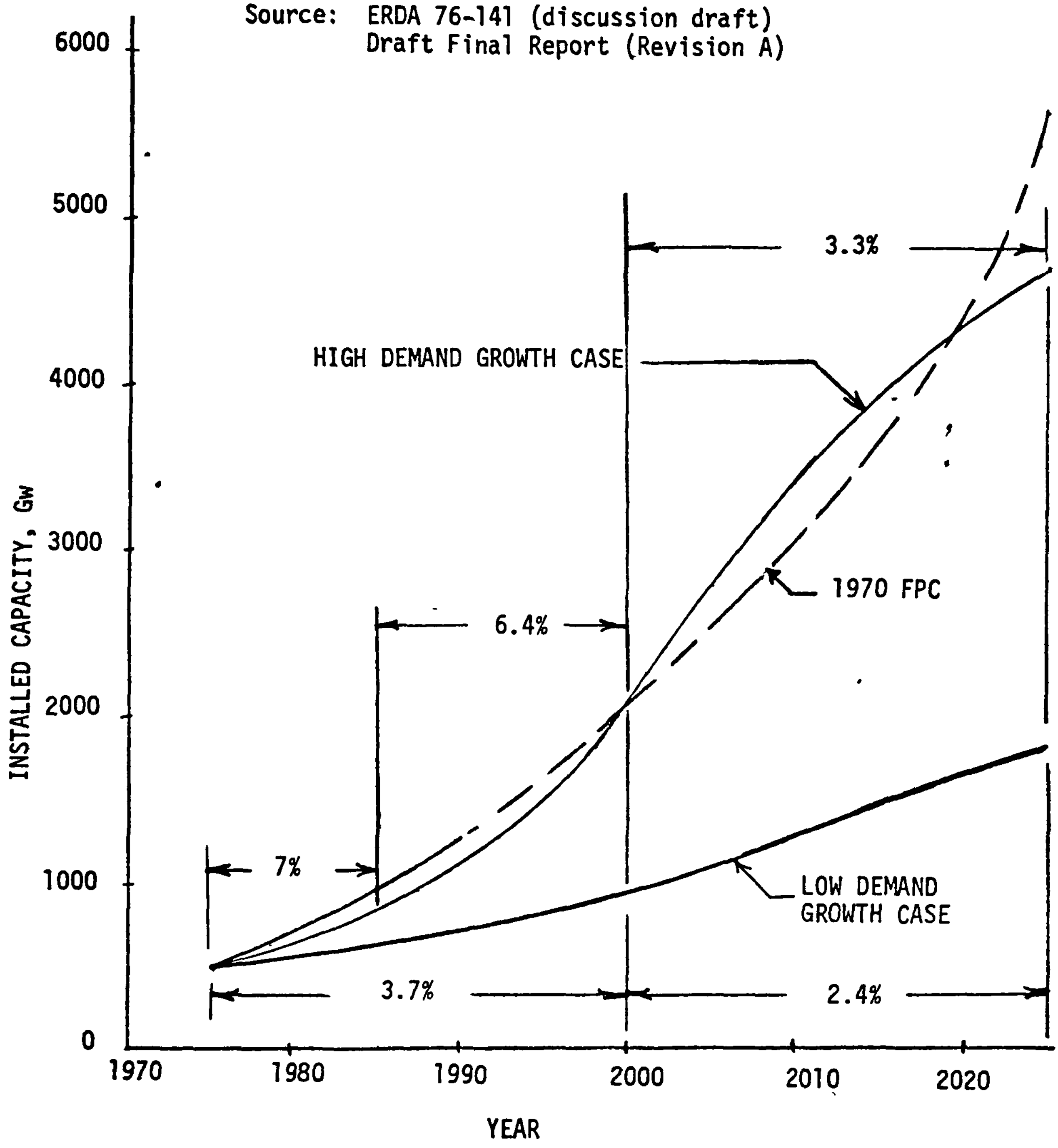


Figure I-1

II. SUMMARY AND CONCLUSION

The summary and conclusions of this year's effort are contained in Volume I of this report.

This Volume (Volume II) contains the individual contributions by the JSC Solar Power Satellite (SPS) study team members. The scenario B defined in the 1976 JSC report on "Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts" was utilized as the basis for study.

III. PROGRAM REQUIREMENTS

III-A. U. S. PROJECTED ENERGY DEMAND

T. E. Redding
Systems Evaluation Off.

JSC's previous in-house SPS study (ref. 1) included a projection of the nation's electrical energy requirements through the year 2025. This projection (shown in figure III-A-1) was based on a Federal Power Commission (FPC) projection through 1990 with an extrapolation by JSC to the year 2025. Numerous other organizations have made projections of electrical energy consumption as indicated in figure III-A-2. For reference purposes, the previously used FPC projection is also shown in figure III-A-2 along with projections by the Department of Interior (ref. 2). "Electrical World" magazine (ref. 3), Shell Oil Company (ref.4), the Electric Power Research Institute (ref. 5) and the Energy Research and Development Administration (ERDA) (ref. 6).

The FPC projection is a pre-1973 oil embargo projection that assumed an historical growth (about 6 percent) rate. As a result it is somewhat higher than the other projections, which include the effects of various levels of conservation. A recent ERDA projection of installed capacity requirements is shown in figure III-A-3. The high demand growth case is similar to the corresponding capacity requirements of the FPC energy demand projection. The assumptions for this ERDA projection are as follows:

a. 7 percent growth rate to 1985.

b. 6.4 percent growth rate from 1985 to 2000.

c. 3.3 percent growth rate from 2000 to 2025.

d. Continuing shift by users from other forms of energy to electricity.

The low demand growth case is based on the following assumptions:

a. 3.7 percent growth to 2000.

b. 2.4 percent growth from 2000 to 2025.

c. Significant conservation efforts and no increased degree of electrification.

As indicated in figure III-A-3, a greater than factor of two difference exists in the projected capacity requirements in the year 2025, depending on the growth rate assumed.

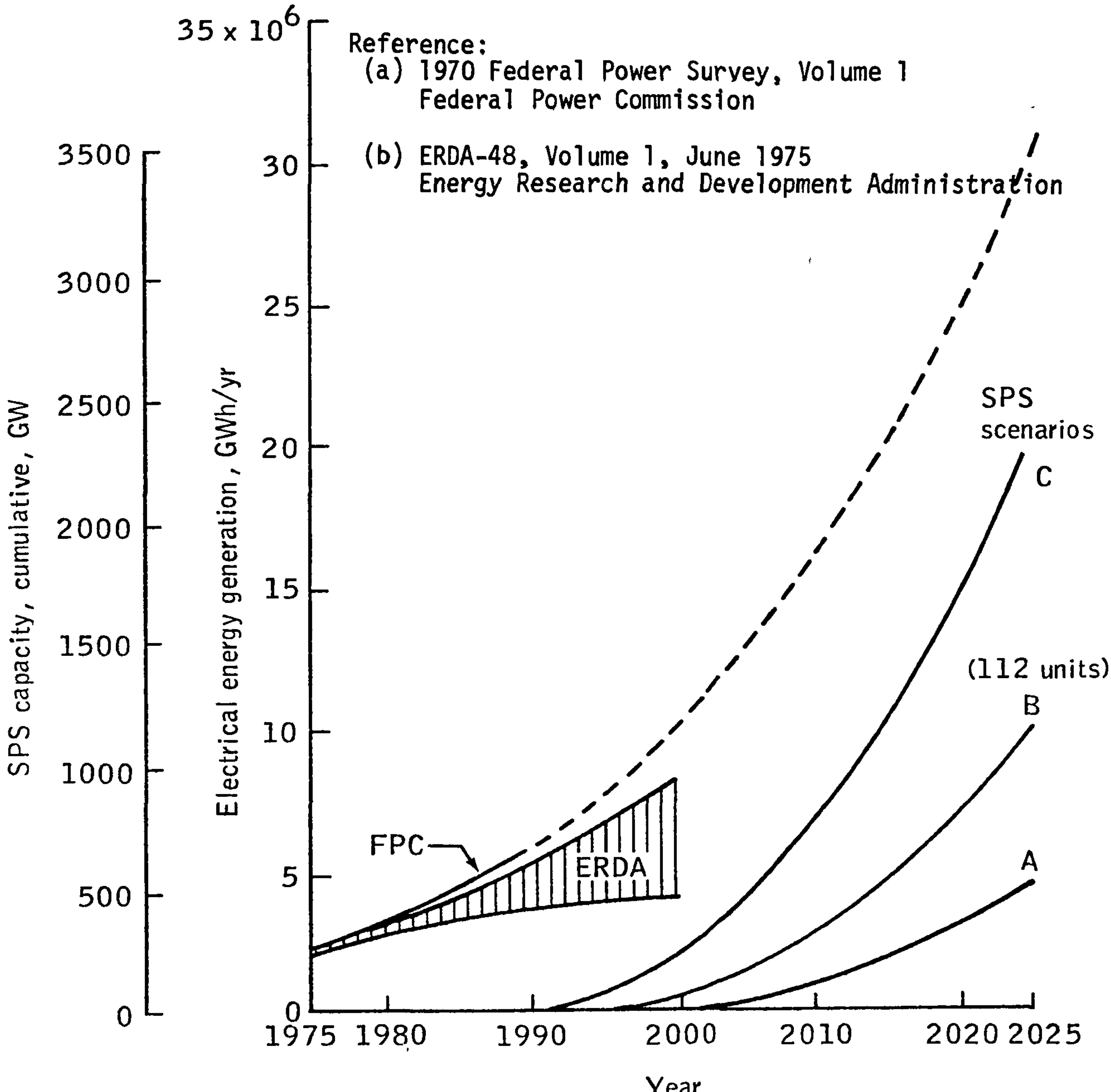


Figure III-A-1 - Projections of U.S. electrical energy requirements and possible SPS implementation scenarios.

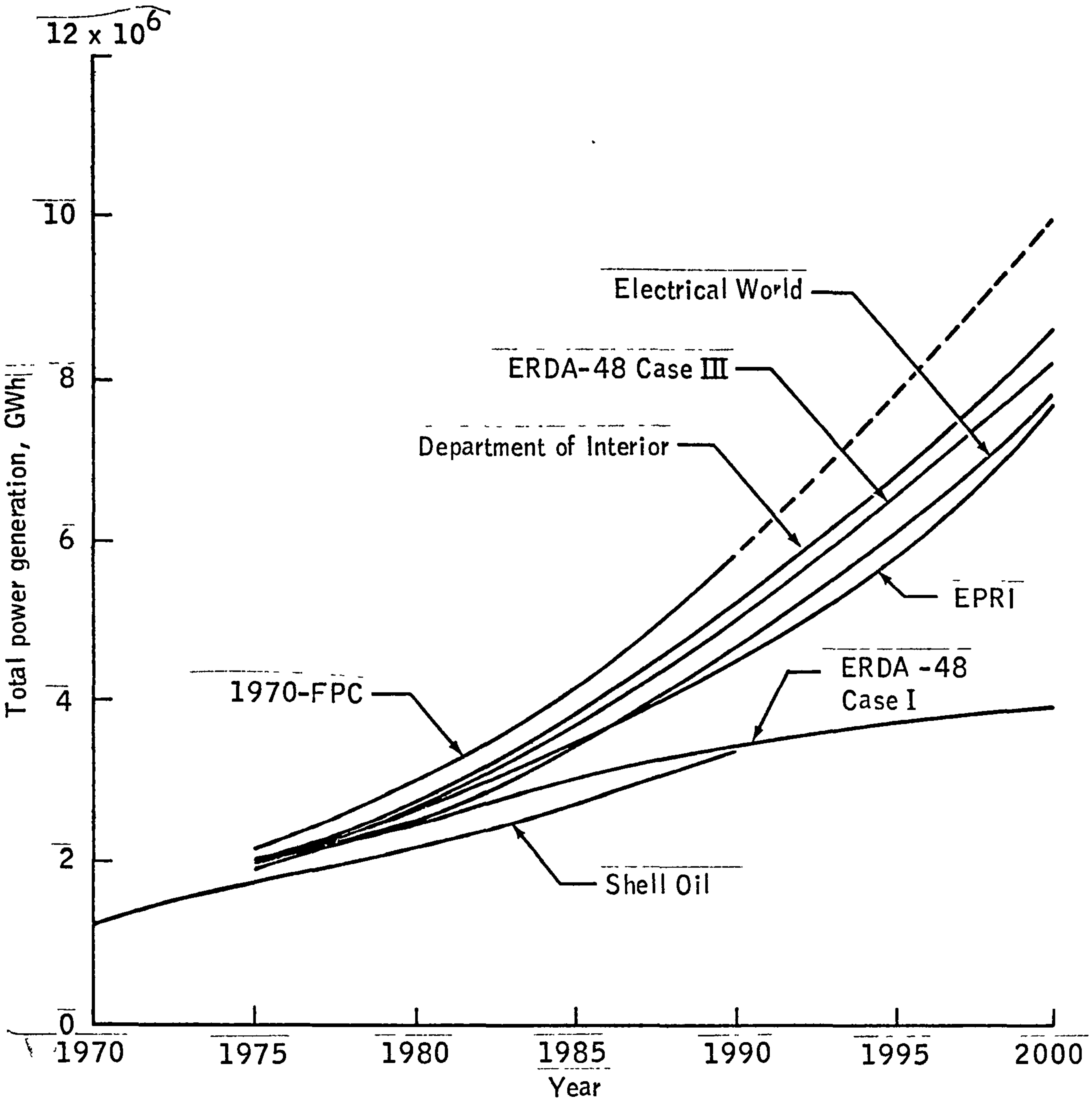


Figure III-A-2 - ELECTRICAL POWER PROJECTIONS BY SEVEPAL ORGANIZATIONS

POWER GENERATION CAPACITY PROJECTIONS

Source: ERDA 76-141 (discussion draft)
Draft Final Report (Revision A)

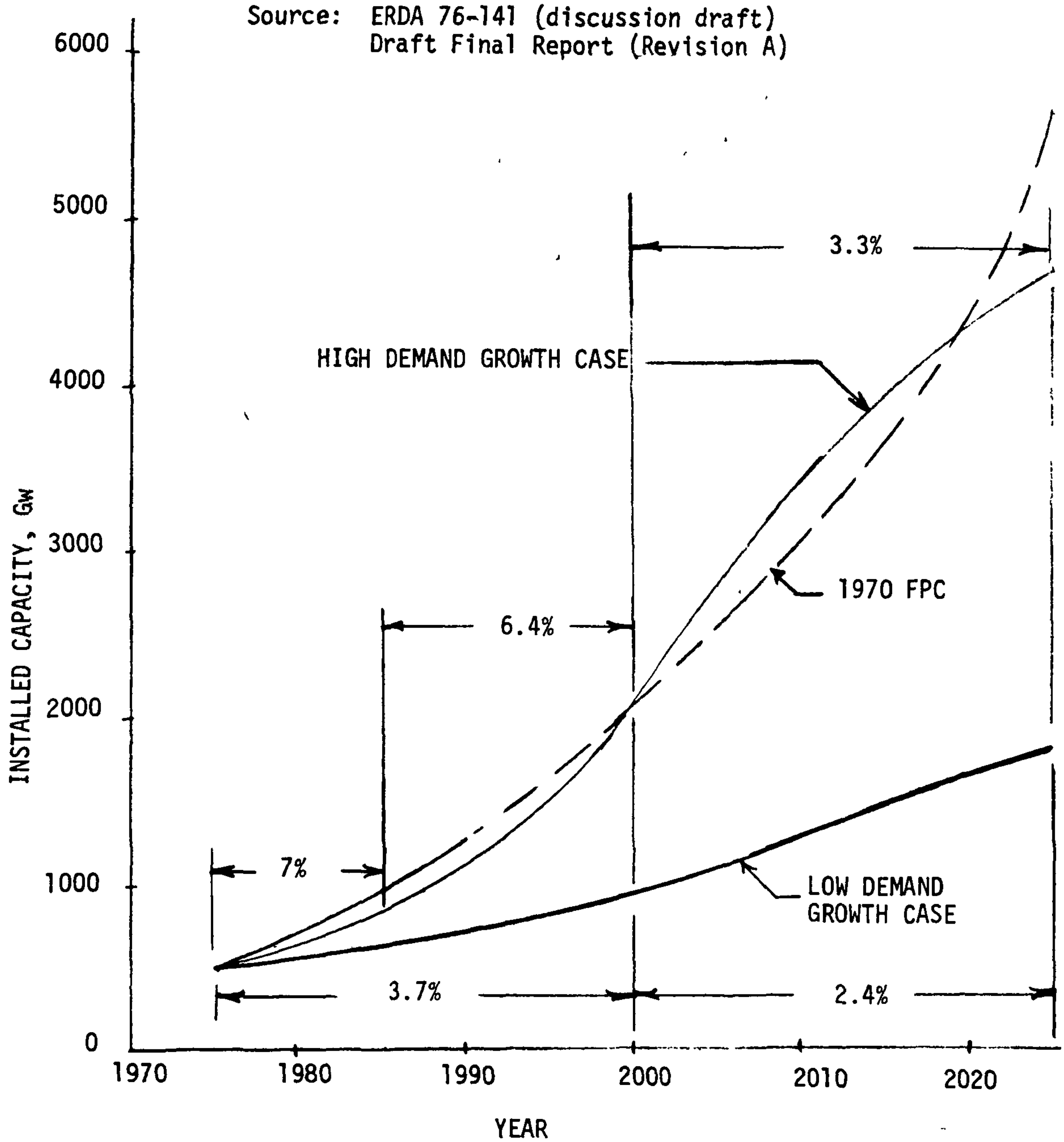


Figure III-A-3

III-B. SPS IMPLEMENTATION IMPACT ON PROJECTED ENERGY DEMAND

T. E. Redding
Systems Evaluation Off.

In JSC's initial SPS study, the SPS implementation rates (shown in figure III-A-1) were developed for study purposes. The three scenarios developed were constructed to provide the following percentage of new capacity requirements.

Scenario A - 25 percent by 2015

Scenario B - 50 percent by 2010

Scenario C - 100 percent by 2005

Scenario B was utilized as an illustrative example to determine program requirements and to perform economic analysis. This scenario results in SPS providing about 30 percent of the projected electrical energy demand in 2025 (FPC projection). Sized at 10 Gw per SPS, a total of 112 satellites would be required in 2025.

In view of the lower demand projections previously discussed, a reassessment of SPS implementation rates was made. The reassessment was based on the ERDA installed capacity projections shown in figure III-A-3. The low demand growth case reaches a capacity of about 1800 Gw and an energy demand of 8.7×10^{12} kwh in 2025. An average SPS installation rate of one 10 Gw unit per year beginning in 1995 would result in an SPS capacity of 300 Gw in 2025 or about 17 percent of the total. At an average plant factor of 0.92, SPS would provide about 28 percent of the electrical energy (kwh) demand in this case. A total of 30 satellites would be required.

The high demand growth case reaches 4700 Gw capacity in 2025. The corresponding electrical energy output is 22×10^{12} kwh. In this case, an average SPS installation rate of three 10 Gw units per year for 30 years would yield 90 satellites producing 7.25×10^{12} kwh (33 percent) with a capacity of 900 Gw (19 percent) in the year 2025.

Based on the above cursory evaluation, it appears that average SPS installation rates of one to three units per year would result in providing significant quantities of electrical capacity and energy in the year 2025. These rates are significantly lower than the peak rate of seven units per year used in the reference scenario B case.

III-C. UNITED STATES RECTENNA SITING CONSIDERATIONS

V. Shields
Systems Evaluation Off.

INTRODUCTION

The most important factor for considering locations of rectenna in the U.S. is population density. Energy demands across the U.S. generally reflect population. Highly populated regions have high energy demands, and Americans are becoming concentrated in localized regions. At the turn of the century, 60 percent of our population lived on farms and in small villages with low population densities. Migration trends to metropolitan areas have been altered such that 71 percent of the population lived in Metropolis by 1970. This number is expected to increase to 85 percent by the year 2000. It appears that metropolitan growth is a basic characteristic of the social and economic transformation of American culture. We have transcended from an agrarian, to an industrial, and now to a service-oriented economy. The lifestyles resulting in the mass move to metropolis will be reflected in increased demands for electricity. This report examines the areas expected to have the largest population densities in the U.S., and looks at possible rectenna locations for the ultimate distribution of electrical energy from a solar satellite power system.

POPULATION

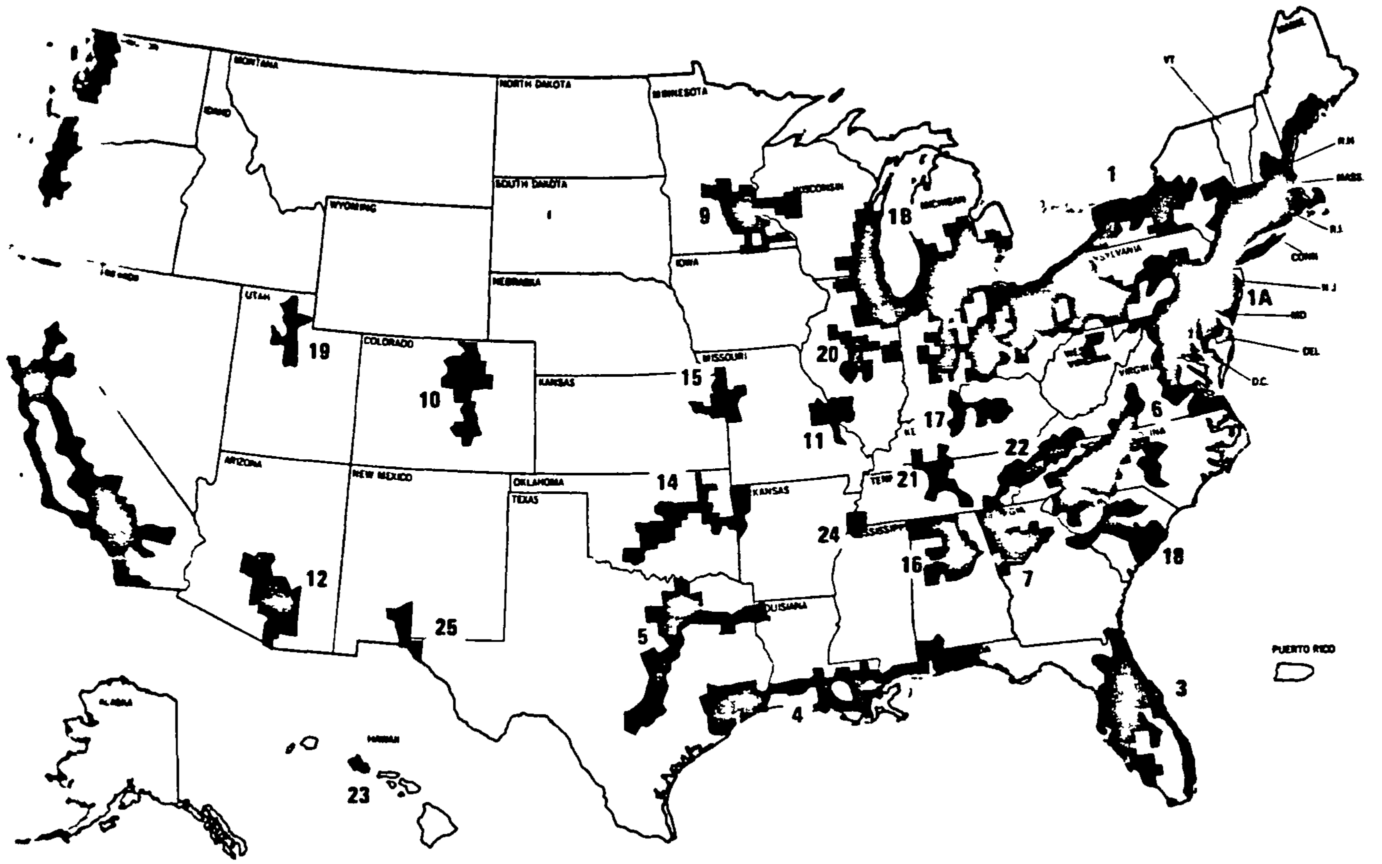
In the year 2000, the metropolitan population is expected to be concentrated in twenty-five major areas in the U.S. These twenty -five areas are given in figure III-C-1 and represent 85 percent of the total U.S. population in that time frame. These figures are based on a two-child family projection and were prepared for the U.S. Commission on Population Growth in 1972 by Jerome P. Pickard.

If our national population distributes itself according to these projections, 54 percent of all Americans will be living in the two largest urban regions. The metropolitan belt stretching along the Atlantic seabord and westward past Chicago would contain 41 percent of our population. Another 13 percent would be in the California region lying between San Francisco and San Diego. The proposed strategy is to consider locating the first rectenna systems in these areas. Specific sites will be determined from geographical and economic consideration associated with land acquisition. Guidelines for establishing the number of rectenna that are feasible is given in Section IV-D-2 of this document.

U.S. ENERGY/POPULATION RELATIONSHIPS

Of the total energy per capita used in this country today, about 30 percent is in the form of electricity. This percentage is expected to increase to approximately sixty by the year 2025, creating a tremendous burden on the existing utility grid structure. Table III-C-1 gives projected population/energy relationships and provides the projected population by regional grid out to the year 2000. Figure III-C-2 shows a map of the U.S. with the regional councils (grids) identified.

Urban Regions: Year 2000

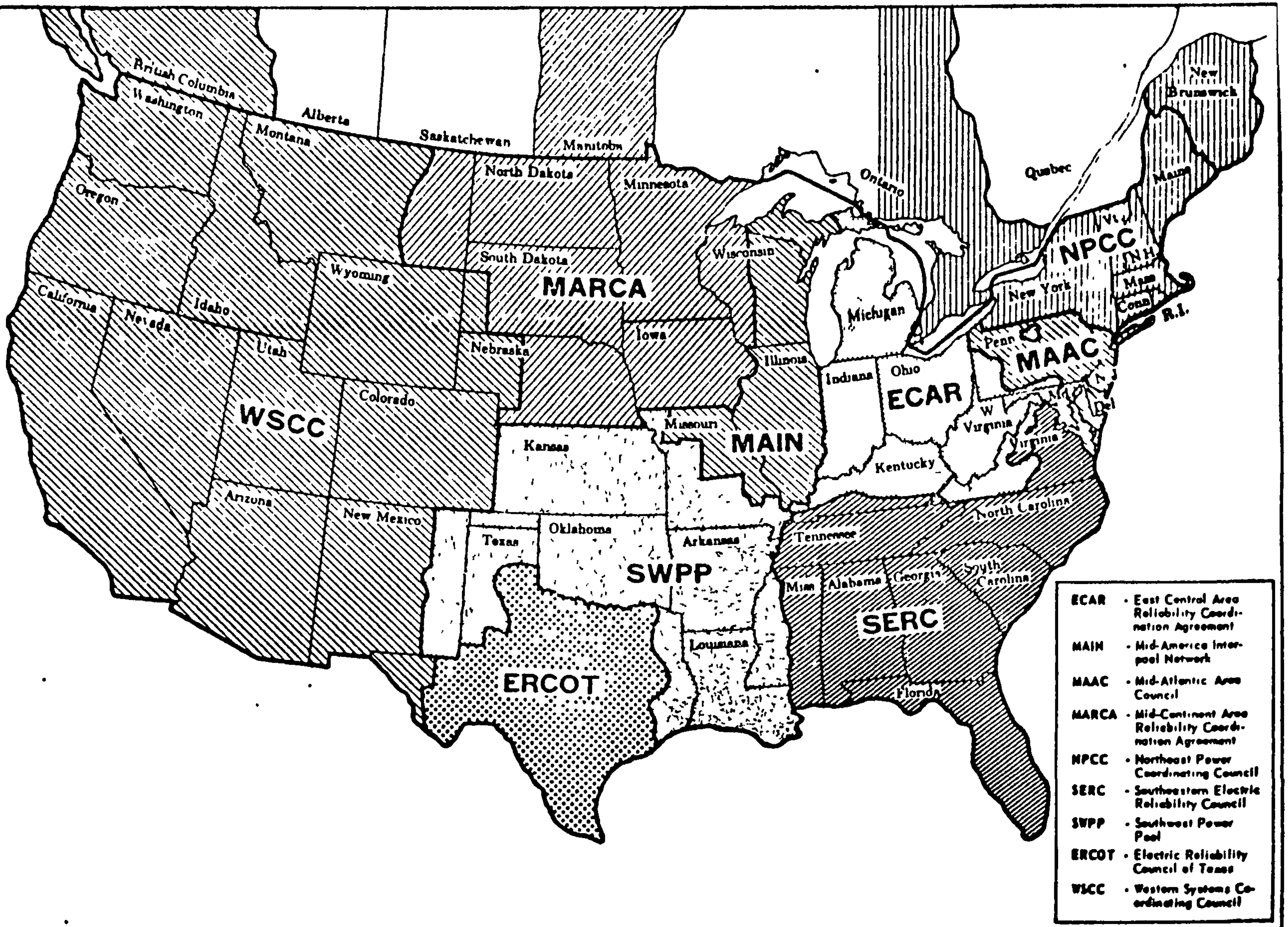


1 Metropolitan Belt
1 a Atlantic Seabord
1 b Lower Great Lakes
California Region
Florida Peninsula
Gulf Coast
East Central Texas—Red River
Southern Piedmont
North Georgia—South East Tennessee
Puget Sound
Twin Cities Region
Colorado Piedmont
Saint Louis
Metropolitan Arizona
13 Willamette Valley
14 Central Oklahoma—Arkansas Valley
15 Missouri—Kaw Valley
16 North Alabama
17 Blue Grass
18 Southern Coastal Plain
19 Salt Lake Valley
20 Central Illinois
21 Nashville Region
22 East Tennessee
23 Oahu Island
24 Memphis
25 El Paso—Ciudad Juarez

Based on 2-child family projection

Source Jerome P Pickard, "U S. Metropolitan Growth an Expansion, 1970-2000, with Population Projections" (preparei for the Commission, 1972).

Figure III-C-1



REGIONAL ELECTRIC RELIABILITY COUNCILS

April 1, 1974

Figure III-C-2

U.S. ENERGY/POPULATION RELATIONSHIPS

	1975	1980	1985	1990	1995	2000	2025
POPULATION (10^6)	213.5	221.5	229	236	242.5	248.5	283
ELECTRICITY USE (10^9 KW-HRS)	2001	2550	3450	4670	6150	7800	27,300
KW-HRS X 10^3/PERSON	9.4	11.5	15.1	19.8	25.4	31.4	87.8
ELECTRICITY AS PERCENTAGE OF ALL ENERGY USES	29.5	29.2	32.4	37.4	43	48.8	59.6
U.S. INSTALLED CAPACITY (GW)	492	620	800	1045	1330	1600	5672
REGION COUNCIL POPULATION PROJECTIONS (10^6)							
ECAR		---		----	----	42.2	----
MAAC		---		----	----	18.5	----
MAIN		---		----	----	19.3	----
MARCA		---		----	----	10.9	----
NPCC		---		----	----	19.9	----
SERC		---		----	----	55.1	----
SWPP		---		----	----	22.2	----
WSCC		---		----	----	44.0	
ERCOT		---		----	----	16.4	----

Table III-C-1

III-D. ELECTRICAL POWER DEMANDS FOR WESTERN HEMISPHERE/WORLD

J. Rippey
Systems Evaluation Off.

The assessment of the future energy requirements of other countries is desirable in the consideration of a major advanced energy system such as the Solar Powered Satellite (SPS). For this preliminary study, several representative major-developed and lesser-developed countries (LDC's) are investigated on the basis of a statistical analysis to determine a projection of electrical energy consumption into the SPS operational time frame.

Long-range projections of energy requirements for any country is an exceptionally venturesome task. Experts who are only looking at estimates for the United States alone generally provide numerous scenarios beyond a few year's time and projections beyond a decade's time are considered highly speculative. Yet, those experts have utilized the most extensive statistical records of any country in the world. With such hazards in mind, this exercise will attempt to provide a general indication of energy requirements in the Western Hemisphere and the World.

This analysis involves the use of population and electrical energy consumption statistical data and historical trends. The United States, Canada, Mexico, and Brazil were chosen as being indicators of Western Hemisphere energy consumption.

1. Population and Population Rates of Change

Figure III-D-1, from reference 7, presents a projection of the world's population growth to the year 2000 assuming constant fertility levels. The figure shows that it took all the recorded time to year 1830 for the world to reach its first billion population. As sanitation improvements spread and scientific medicine developed, the world reached its second billion in only a hundred years.....about 1930. With rapid advances in medicine, including the discovery and widespread use of antibiotics, the third billion was reached in just 30 years.....1960. The fourth billion was reached in half-the-time, 15 years.....1975. By the year 2000, it is projected to take about 3 years to add a billion people.

The United Nations is actively involved in accumulating population statistics and trends. They are also providing information and services for countries to control their birth rates. Figure III-D-2 illustrates numerous scenarios of world population projections based on various fertility rates. It shows that if a level of fertility required to replace the parental generation....that is, a Net Reproduction Rate of Unity (NRR=1), implying an average of 2.1 to 2.5 children per couple; depending on mortality conditions.....was reached in the reasonably near future, population would continue to grow for many decades until Zero Population Growth (ZPG) came about.

Several scenarios of fertility rate decline for Mexico are shown in figure III-D-3 to show the population growth potential of lesser-developed major country in this hemisphere.

THE WORLD'S POPULATION GROWTH

PAST AND PROJECTED

(ASSUMING CONSTANT FERTILITY LEVELS)

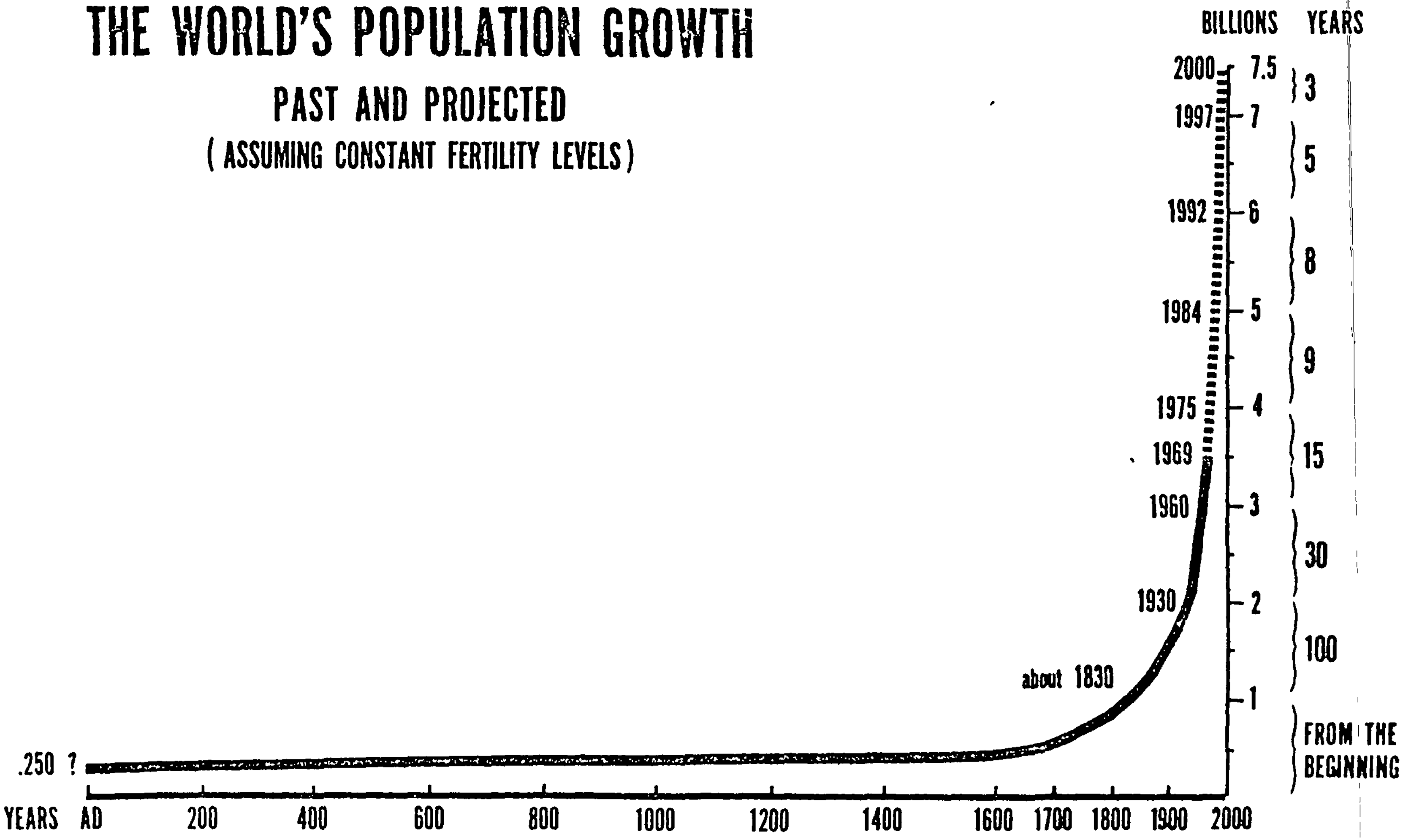
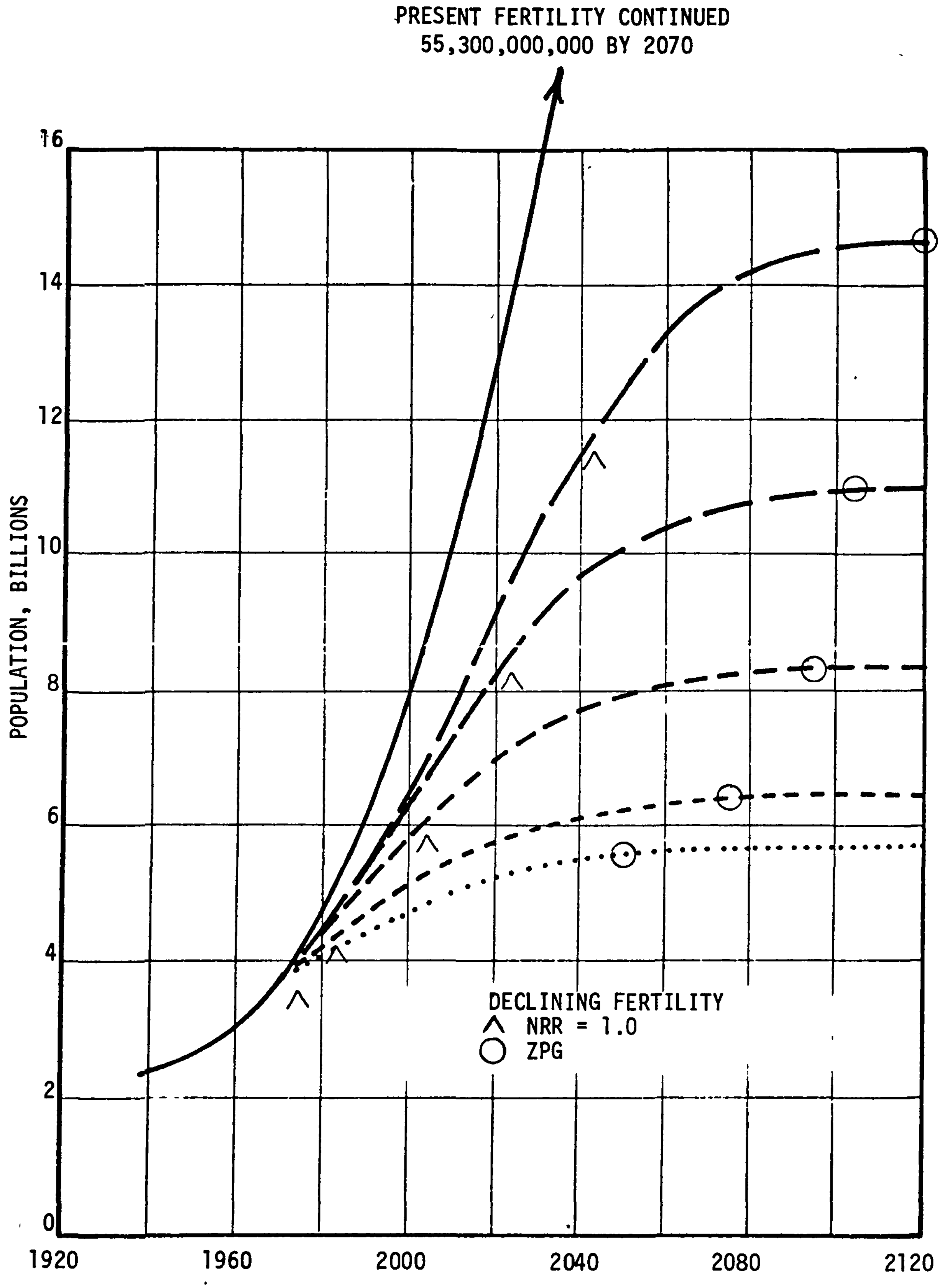


FIGURE III-D-1

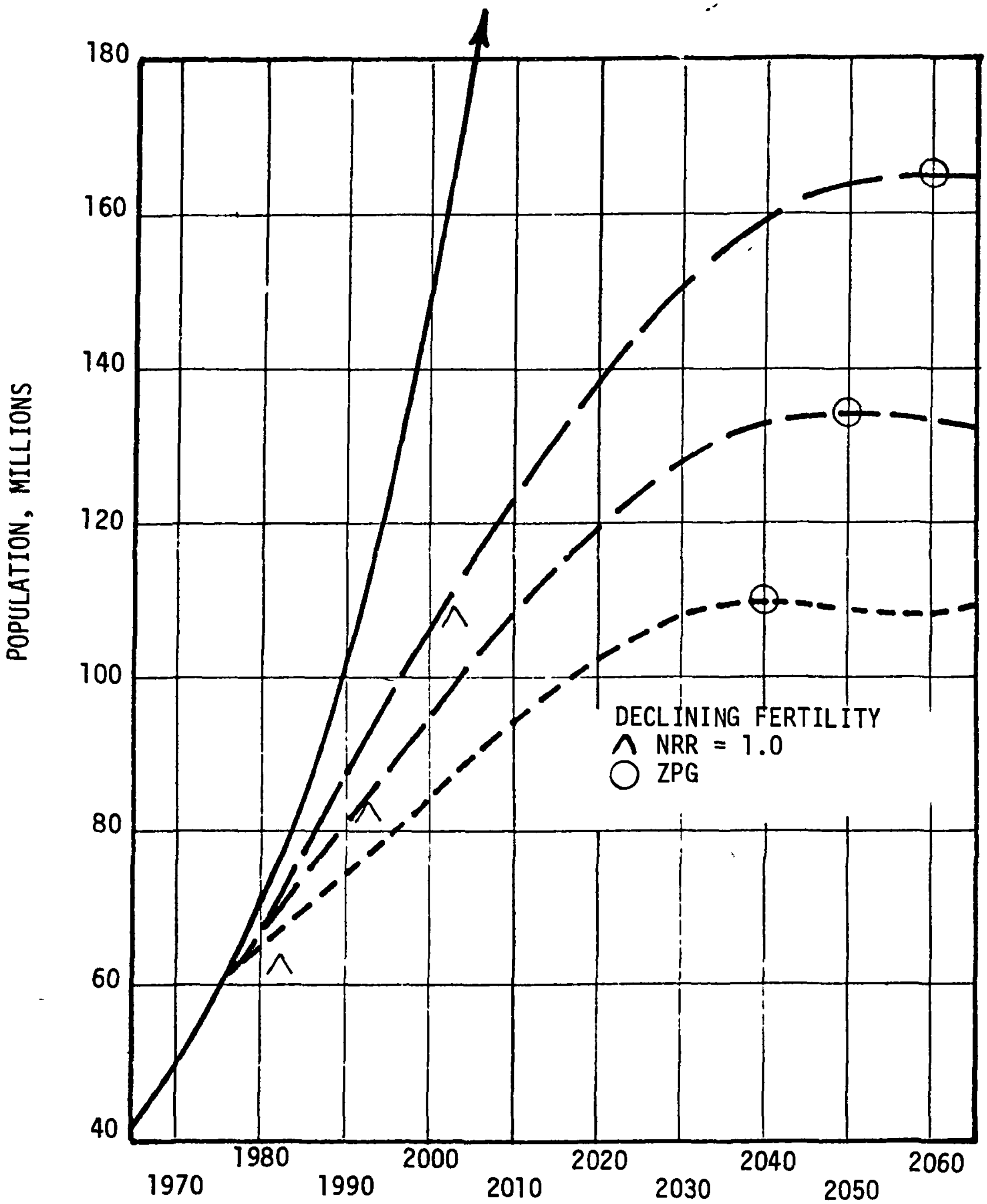


THE WORLD'S MOMENTUM OF POPULATION GROWTH

Figure III-D-2

PRESENT FERTILITY CONTINUED

2,200,000,000 BY 2070



THE MOMENTUM OF POPULATION GROWTH IN MEXICO

Figure III-D-3

In order to obtain energy consumption requirements into the next century, estimates on population growth are needed. The following assumptions are made to obtain a population estimate;

a. Presently the growth rate of the world's population is about 2 percent per year. Brazil is currently experiencing about 3.2 percent increase and Mexico 3.5 percent. According to ref. 8, the NRR for Brazil was 2.3 and for Mexico 2.5 in 1970. Due to the momentum of these increases, for this analysis both countries are expected to reach NRR = 1.0 about year 2003 with ZPG by year 2060. This is one of the scenarios shown in figure III-D-3 for Mexico.

b. Recent U. S. Census Bureau releases show that our population growth rate is declining, citing a 1.1 percent growth rate in 1970, 0.8 percent in 1975 and 0.7 percent in 1976. These figures include immigration quotas which correspond to an annual increment of about 0.2 percent. Canada's growth rate is currently about 1.1 percent according to ref. 8. Both countries had a NRR = 1.1 in 1970 and, for this analysis, are assumed to reach NRR = 1.0 within the decade.

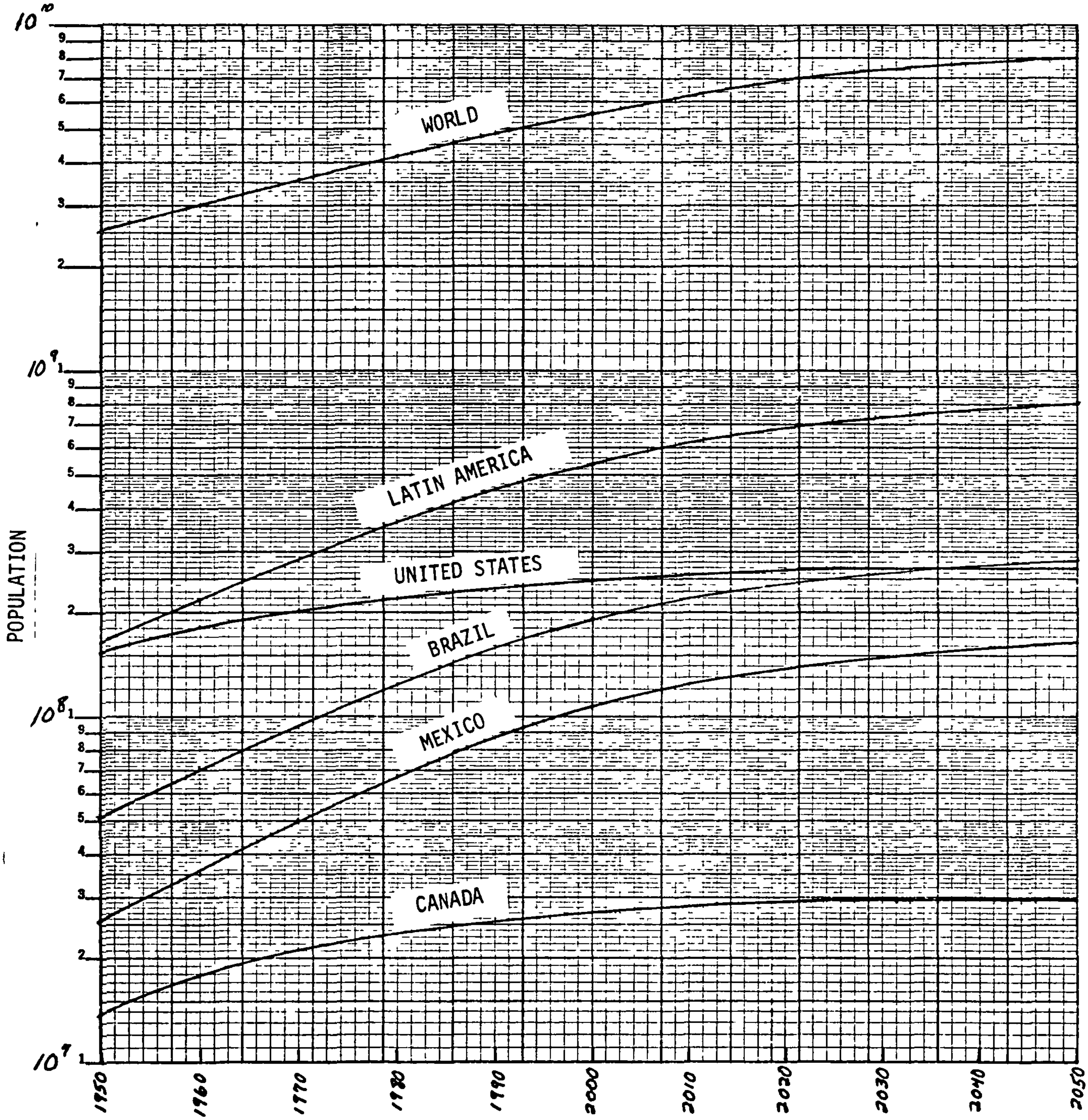
c. Latin America and the world's population growth rates are dictated primarily by the developing countries and, therefore, projections follow closely their rate trends. Historically, however, most long-range demographic projections have erred on the low side. Reference 9 suggests that the U.N. "low variant" predictions should be used into the next century because "a drastic rise in the death rate will either slow or terminate the population explosion, unless efforts to avoid such a tragic eventuality are immediately mounted." Reference 9 indicates that such efforts are underway. Since 1965, programs to slow down rates of population growth in over 80 percent of the under-developed and developing countries have been initiated. Therefore, for this study, the U.N. "low variant" projection is used.

Utilizing the fore-mentioned assumptions and the corresponding fertility rates, figure III-D-4 has been constructed to show the population levels for each of the candidate countries and areas to the year 2050. The historical data shown on the figure from 1950 to the present was extracted from ref. 10.

The figure shows that by year 2035, Mexico will have reached the population level experienced by the United States in 1950 (152 million) and Brazil, at the same time, will have surpassed the United States as the most populous country in the western hemisphere with a population over 270 million. Both of these events will occur earlier if the "low variant" projections prove to be over-optimistic.

2. Electrical Energy per Capita Consumption

An assessment of a nation's energy consumption and future energy requirements frequently is the result of extensive record keeping on a great



WORLD POPULATION PROJECTION IN COMPARISON WITH SEVERAL DEVELOPED AND DEVELOPING REGIONS ON THE AMERICAN CONTINENTS

Figure III-D-4

many energy sources. A simpler indicator of the overall energy picture is the consumption of electrical energy. This is because there generally are fewer energy sources used for electrical energy generation and there are better records available on its production. For these reasons, this study deals only with electrical energy although correlation with the overall energy picture is evident.

Figure III-D-5 graphically illustrates the per capita Electrical Energy Consumption Statistics and Projections from 1950 to 2020 for the selected countries. The statistical data was selected from references 11 and 12. The straight line projections for all of the study areas were derived by determining the rate of change in per capita electrical consumption for the 1970 to 1975 period and applying the same rate in 5 year increments from 1980 to 2020. The 1970 to 1975 period includes the first effects of the oil embargo and fuel price escalations and serves as a very simple indicator of future energy consumption patterns. Of the countries illustrated, it is apparent that the United States felt the effects of the high fuel prices the most. U.N. data shows in recent years (1973 & 1974), Brazil annually imported over 73 percent of its primary energy, Mexico about 11 percent, and the United States about 17 percent. Because of our extensive industrial base, the rapid increases in energy costs obviously produces a more noticeable effect on our industrial growth rate. Although Canada was also effected by the higher fuel costs, their per capital electrical energy consumption indicates no noticeable effect. Investigation of their energy self-sufficiency shows that they were able to export energy during the entire 1970 to 1975 period, thus helping to continue their pre-embargo per capita energy growth rate. Another notable trend in figure III-D-5 is the similarity of the United States and the world's energy consumption per capita. Apparently most of the developed nations felt the major effects of rapid fuel cost increases. Certainly the United States, with less than 6 percent of the world's population, but currently utilizing about 30 percent of the world's consumed energy, is the major factor in this parallel.

The simple fixed rate method used in the electrical energy projections excludes the effects of major variables such as significant changes in population rates and major energy resource discoveries. The effects of dwindling energy supplies is not reflected here other than in the large cost increase during the early 1970's and the resulting rate projections.

Utilizing the population projections from figure III-D-4 and the per capita electrical energy consumption values shown in figure III-D-6, table III-D-1 was constructed to show the sharp increases of energy needs from 1960 to year 2020. In the 60 year period, the world's electrical energy consumption is shown to increase by a factor of 26 over the 1960 level. The United States' consumption will multiply almost 13 times, Brazil 75 times, and Mexico 117 times. Early into the 20th century, both Mexico and Brazil will require energy levels currently consumed in the United States. It should be realized that the following table is based on constant rate increases of electrical energy consumption indicated by

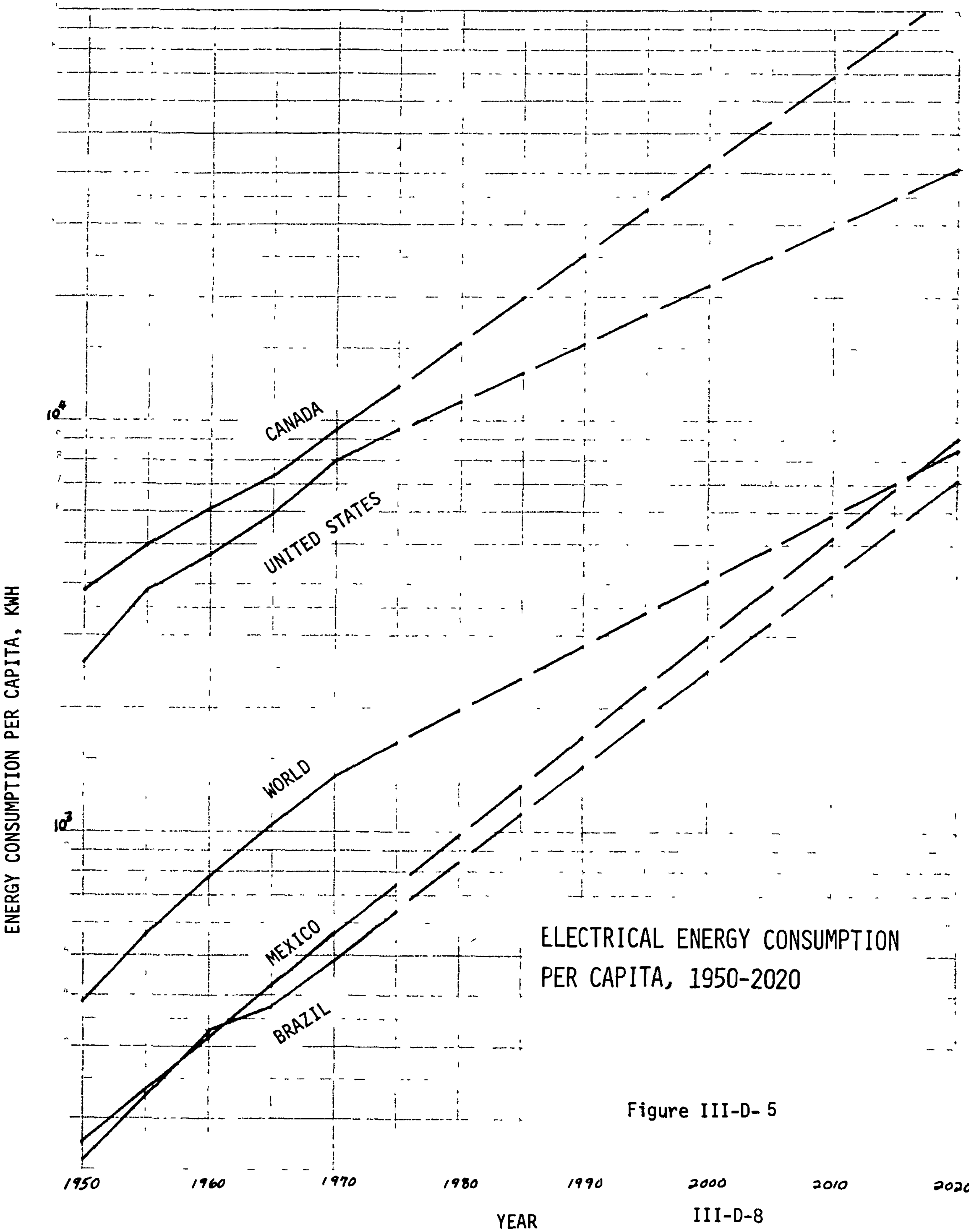


Figure III-D- 5

energy availability of recent years. Assuming the gap between energy supply and demand will continue to narrow, increased competition for the available energy will become more pronounced.

TABLE III-D-1

	1960	(1975)	1980	2000	2020
World	2301	6236	8199	22701	61021
U.S.A.	844	1982	2444	5296	10875
Canada	114	273	365	1149	3316
Brazil	23	69	104	474	1721
Mexico	11	43	67	325	1266

TOTAL Electrical Energy Consumption from 1960 to 2020 in KWH X 10^9

III-REFERENCES

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IV. SATELLITE POWER STATION

Clarke Covington
Spacecraft Design Division

This section presents the results of the in-house and contracted efforts which together make up the SPS system definition and concept evaluation study for the power station (including the rectenna). The contracted part of the study was funded with $500K in FY76 funds allocated for SPS system definition as defined in Section IX-A of this report. The contracted studies and where their results are summarized are as follows:

- SPS System Definition - $375K (Section IV-A)
- Phase Control System Hardware Simulation - $40K (Section IV-C-2-b)
- Klystron Evaluation - $15K (Section IV-C-2-a)
- Solar Cell Evaluation - $20K (Section IV-B-1-b)
- Rectenna Structural Design - $10K (Section IV-D-3)

In addition, the following two studies were also funded which derived data useful in the development of design criteria for the SPS system:

- GEO Radiation Environment Analysis - $10K (Section VII-B-1-a)
- Energetic Particle Precipitation - $15K (Section VII-B-2)

Most of the results included in this section are primarily a collection of individual studies related to specific areas of special interest rather than an "across-the-board" analysis of the total satellite system as was last year's system definition study.

A. SATELLITE SYSTEMS DEFINITION

Most of the SPS system definition work in this period was done in the first part of a two-part study contracted to Boeing ("SPS System Definition Study", NAS 9-15196). Part I of the study began November 22, 1976 and ended May 1, 1977, and had as its objectives the development of comparative data to aid NASA in the evaluation of two basic questions which remained after the 1975-76 JSC in-house study report. These two major questions were:

1) What is the overall most effective means of accomplishing solar energy-to-electrical energy conversion on an SPS in geosynchronous orbit?

2) At what location (or locations) in space should the various phases of SPS construction and assembly be done?

As a point of departure, two reference configurations were established at the beginning of the study. These were the JSC planar truss photovoltaic system described in the August 31, 1976 JSC study report (JSC-11568), and the Boeing Brayton thermal engine system developed in a 1976 study for MSFC (NAS 8-31628).

Energy Conversion Question

A range of energy conversion candidates was considered which included the following:

Photovoltaic

- Single Crystal
  - Silicon
  - Gallium Arsenide
- Advanced Thin Film
  - Silicon
  - Gallium Arsenide
  - Cadmium Sulfide
  - Copper-Indium Selenide

Thermal Cycle

- Brayton
- Modified Brayton
- Rankine
- Thermionic

A comparative evaluation was made of these candidates using a set of evaluation factors designed for relative assessment of each candidate. These evaluation factors, or "comparators", were:

- SPS performance
- Performance degradation
- SPS size
- SPS mass
- System complexity
- System maintainability

- Construction requirements
- Transportation requirements
- Technology advancement requirements
- System cost differential factors
- Environmental effects differential factors
- Materials differential factors

The results of the energy conversion evaluation can be summarized as follows:

(1) There are at least four viable energy conversion candidates: photovoltaic silicon, photovoltaic gallium arsenide, thermal Brayton cycle, and thermal Rankine cycle.

(2) Thermal engines are more complex, but require less technology advancement.

(3) Photovoltaics are simple in concept, but a continuous production process for solar cells must be developed or the concept is impractical.

(4) There are no large differences in DDT&E or production cost projections for energy conversion between the four viable candidates.

Part II of the Boeing study will produce a complete SPS system definition with each element of the system defined to the same level. A goal of the study is to reduce the range of uncertainty in the weight and cost estimates to one-half the range developed in the 1976-77 JSC study. To do this, the number of energy conversion candidates must be reduced to those which show the promise of being most effective considering all factors, and then doing the more detailed system definition with those selected concepts.

Boeing's recommendations concerning energy conversion, for the purposes of Part II of this study are as follows:

(1) As a Part II study reference or "baseline", proceed with both the photovoltaic silicon system (with concentration ratio of one and annealable), and a thermal engine system using the Brayton cycle. (The Rankine cycle may, in time, supplant the Brayton cycle if recent significantly reduced weight estimates for Rankine turbine compressors for use in space can be substantiated.)

(2) The photovoltaic Gallium Arsenide system concept should be carried into Part II of the study as an advanced technology option.

(3) The potential for a large mass reduction in the thermal engine system using the Potassium-Rankine cycle should be further evaluated.

(4) Thin-film photovoltaic systems should be discontinued in this study until a better data base is available.

(5) The steam Rankine system and the thermionic system should be dropped because of their relatively high masses.

The detailed results and supporting analyses of the energy conversion evaluation may be found in the Boeing final report of Part I, published in June 1977, and in Section IV-B of this report.

Construction Location Question

In the consideration of where the construction of an operational SPS should be accomplished, the primary choices are low earth orbit (LEO) below the earth's radiation belt, geosynchronous equatorial orbit (GEO), or some combination of the two. The most significant difference between the two locations is that LEO construction allows a low-thrust transfer from LEO to the operational GEO location using a high-Isp electric propulsion system installed on the SPS and powered by the part of the *operational electric generating capability of the SPS itself.*

Several factors favor GEO construction. Atmospheric drag effects are negligible and gravity gradient forces are much less severe. Construction can take place in near-continuous sunlight. The SPS design does not have to accommodate transfer loads or the installation of the transfer propulsion system. The risk of collision with other orbiting objects during construction and transfer is nearly eliminated. Although orbital transfer with chemical systems are less efficient, they are well known and much quicker than electric systems.

On the other hand, LEO construction has the potential of considerably reducing the launch rate and overall transportation requirements, and could be about 25 percent lower in overall transportation costs.

A summary of the evaluation factors for the construction location question and the associated relative merits of the two alternatives is shown in Table IV-A-1.

EVALUATION FACTOR	PREFERRED CONSTRUCTION LOCATION		DECISION DRIVER
	LEO	GEO	
a) TRANSPORTATION REQUIREMENTS	●		LEO REQUIRES LESS FLIGHTS AND LESS ON-ORBIT PROPELLANT TRANSFER
b) CONSTRUCTION REQUIREMENTS	NO SELECTION		'LEO DRAG & DARK PERIODS VS. GEO RADIATION & DISTANCE
c) SPS OVERALL DESIGN REQUIREMENTS		●	LEO REQUIRES MODULARIZATION & OTHER SPECIALIZATION
d) SPS PERFORMANCE AND DEGRADATION POTENTIAL		●	DEGRADATION DUE TO VAN ALLEN RADIATION CAN BE COMPENSATED
e) LAUNCH SITE DIFFERENTIAL EFFECTS	●		FEWER LAUNCHES FOR LEO
f) SYSTEM STARTUP REQUIREMENTS		●	LEO STARTUP MORE COMPLEX
g) OPERATIONS CONSIDERATIONS		●	LEO HAS MORE DISTINCT KINDS OF OPERATIONS
h) COLLISION CONSIDERATIONS		●	ABOUT 15 COLLISIONS/SPS FOR LEO VS 2 FOR GEO
i) SYSTEM COST DIFFERENTIAL FACTORS	●		LEO ABOUT 25% CHEAPER OVERALL TRANSPORTATION
j) ORBITAL TRANSFER COMPLEXITY FACTORS		●	ELECTRIC PROPULSION (LEO) MORE COMPLEX

TABLE IV-A-1

The results of the construction location evaluation are that either LEO or GEO construction is a viable option, but there is no clear choice at this time. It is possible that both modes would be used, depending upon requirements other than technical. Boeing's recommendation for Part II of the study is to defer the decision until program requirements are more clear. For the construction facility analysis, the recommendation is to use a modular SPS construction concept which would be required for GEO construction and is a viable approach for GEO construction also.

The detailed results and supporting analyses of the construction location evaluation may be found in the Boeing final report of Part I, published in June 1977.

IV. SATELLITE POWER STATION

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B. SOLAR ENERGY COLLECTION SYSTEM (SECS)

1. Energy Conversion

a. Energy Conversion System Comparison - Most of the past year's work in evaluating the relative merits of the various candidate energy conversion concepts was done in Part I of the SPS System Definition Study contracted to Boeing (NAS 9-15196). This study began by taking as points of departure the truss configuration with single-crystal silicon solar cells (CR=2) which was developed in the 1976 JSC in-house study, and the Brayton thermal cycle system developed by Boeing in a study for MSFC. These reference systems were used in comparative analyses of transportation and construction alternatives. The evolution of these analyses and the resulting configuration concepts are shown in figure IV-B-1.

A comparative evaluation was made of the energy conversion candidates listed on page IV-A-2 by using the set of evaluation factors (also on page IV-A-2) derived for relative assessment of each candidate. A summary of the results of each evaluation factor is given in the following:

SPS Performance - Initially it was believed that the thermal engine systems were much more efficient overall than the photovoltaics; however, the difference is not nearly as large as first thought. Efficiency of a system generally follows technology advancement, and the systems with more development tend to show up as more efficient. As it turns out, in the overall system performance evaluation, efficiency is not a major discriminator unless it is very low. Efficiency comparisons are shown in figure IV-B-2.

Performance Degradation - Every candidate system is subject to radiation degradation, but to varying degrees. The thermal engine systems suffer the least, followed by the gallium arsenide and then silicon photovoltaic systems. The left side of figure IV-B-3 shows how the output of these candidate systems degrades with time, while the right side presents the degradation normalized to show what percentage of total satellite mass is affected by the degradation. For example, the thermal systems degrade because of the gradual loss of reflectivity in the thin film concentrators which account for only a small part of the total satellite mass. For all the recommended concepts, degradation was compensated for in some way for the system comparisons, whether by initially oversizing, periodic adding on more energy collecter, by annealing or some other maintenance. This compensation can be represented by size, mass, and cost, which makes radiation degradation relatively unimportant as an independent evaluation factor.

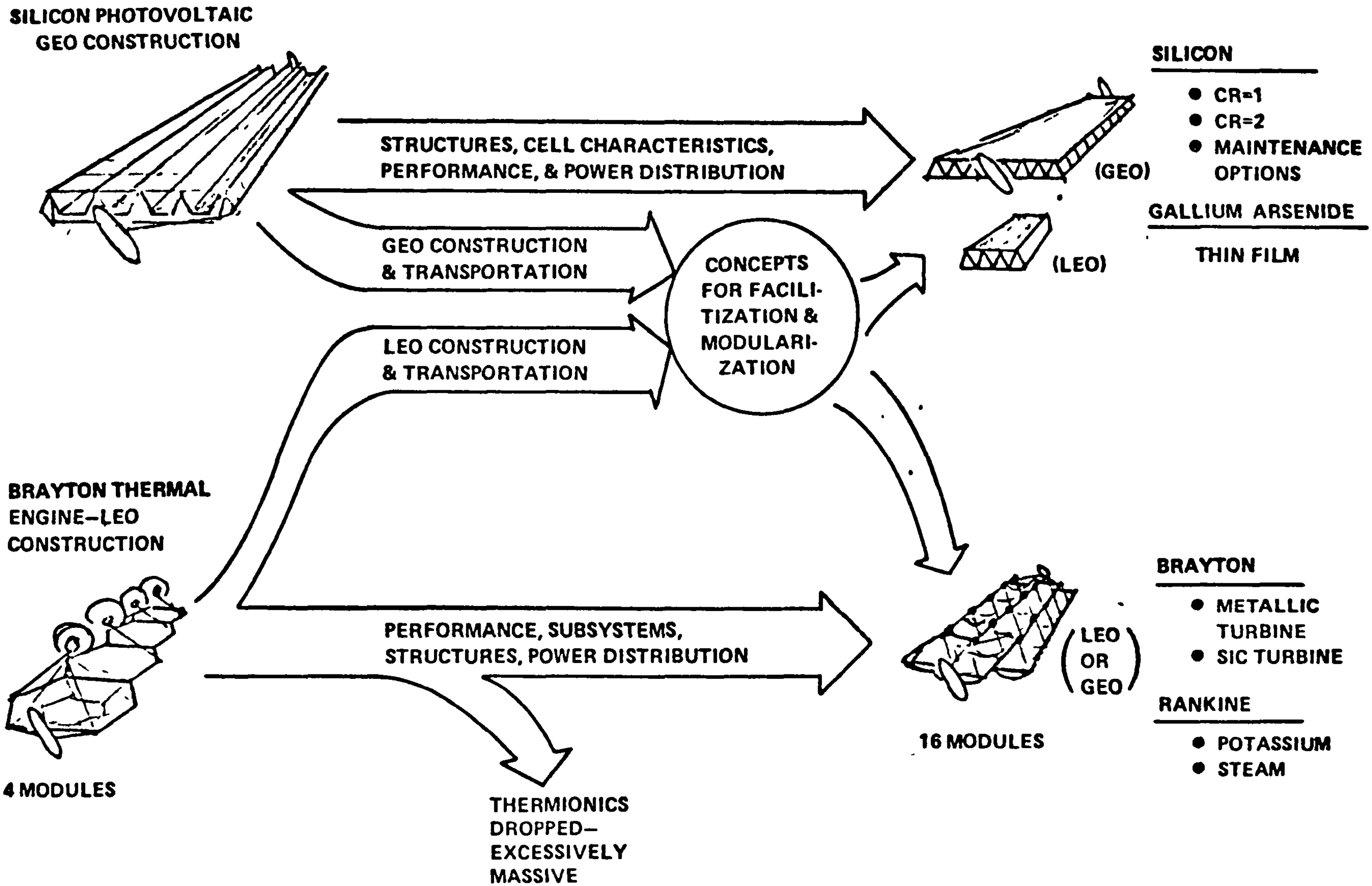

FIGURE IV-B-1 - ANALYSIS AND CONFIGURATION EVOLUTION

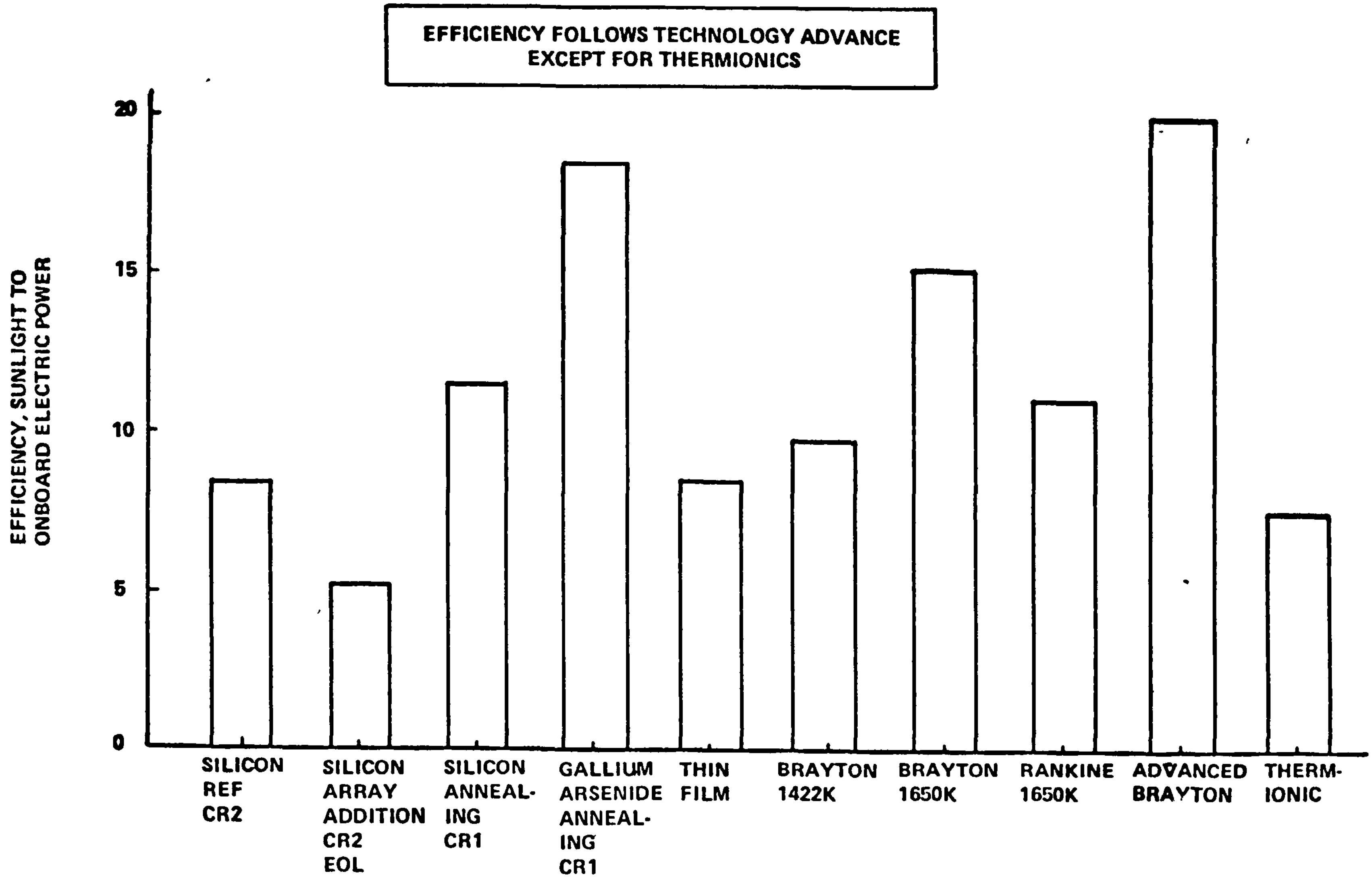

FIGURE IV-B-2 - PERFORMANCE COMPARISON OF ENERGY CONVERSION CANDIDATES

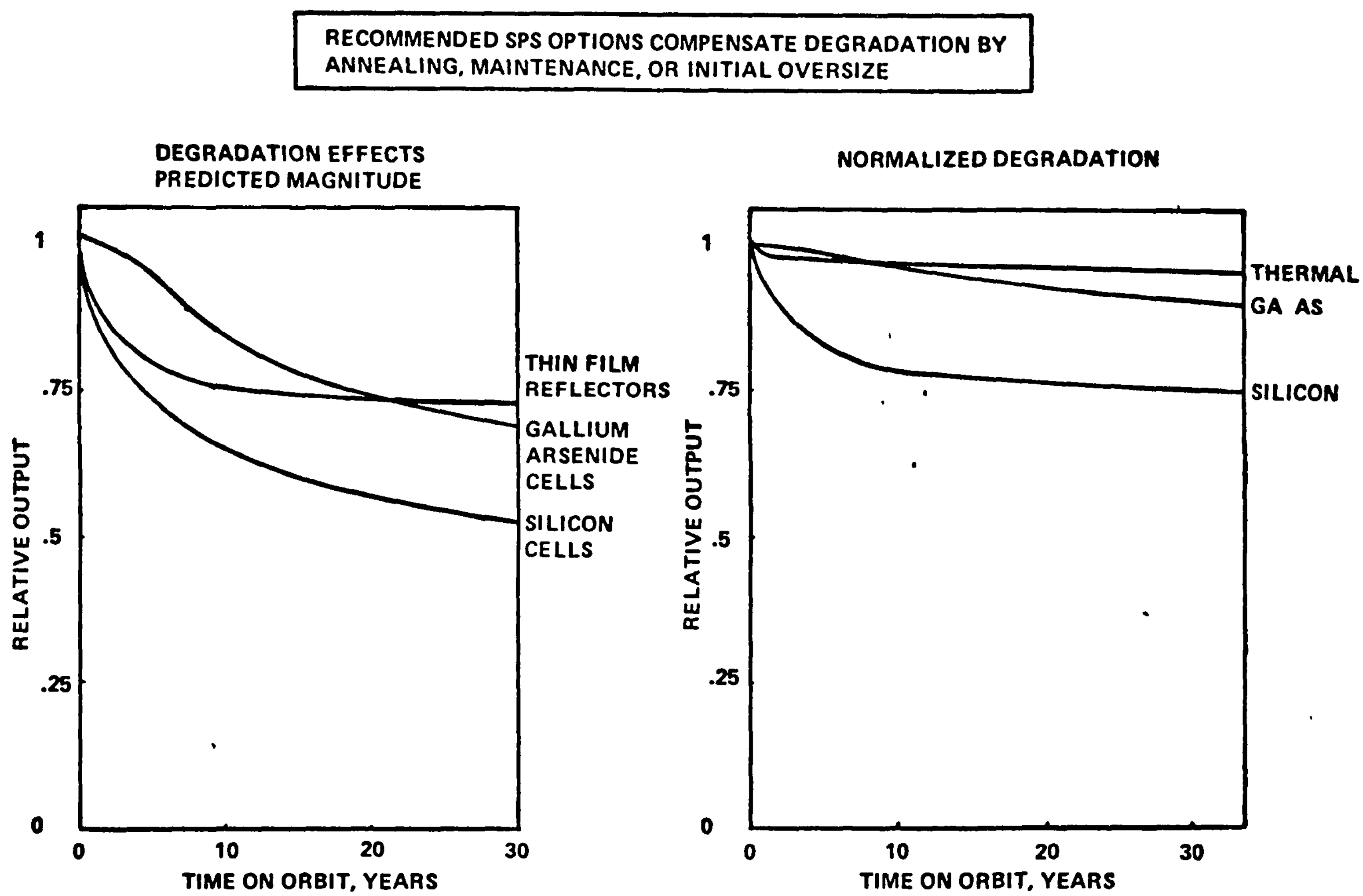

FIGURE IV-B-3 - PERFORMANCE DEGRADATION COMPARISON

Satellite Size - As shown in figure IV-B-4, an annealable gallium arsenide system has the smallest area with the Brayton system ranking second. Silicon systems with no concentration (CR=1) are considerably smaller than those which have a concentration ratio of two (CR=2). The estimate for thin film photovoltaics is much more uncertain than the others because less data is available for these systems today. Total planform area does not seem to be as strong a discriminator as some others.

Satellite Mass - Figure IV-B-5 shows a relative mass comparison with no margin included in the totals. The reference silicon (CR=2) system was sized for a beginning-of-life (B.O.L.) output of 10 GW total and, for reference, carried no penalty for maintaining a relatively constant output. This comparison clearly shows the tremendous potential advantage in having the capability to anneal radiation damage to restore initial conditions as opposed to periodically adding new energy collector to maintain B.O.L. power output. Initial tests were made of an annealing concept which uses an electron beam to heat the outer, damaged part of the solar cell momentarily with a directed energy pulse without any significant heat diffusing into the substrate. Initial estimates indicate that about six remotely-operated annealing machines, each about 2m square by 3m long, could keep the performance of a silicon photovoltaic system near 100 percent by continually traveling the surface of the solar array.

The lightest concept was the gallium arsenide system. Both the steam Rankine and thermionic systems were so heavy that it is recommended that they be dropped from competition.

System Complexity - Complexity is difficult to quantize. For instance, the thermal systems have about five times as many unique parts or subassemblies as the photovoltaic systems. However, the photovoltaics are made up of 1000 times as many total pieces. Since integration complexity of systems is usually a function of the number of unique parts, the thermal systems are considered more complex than the photovoltaic systems. The complexity comparison is represented pictorially in figure IV-B-6.

Maintainability Factors - Every candidate system has potential maintainability problems, but, when the systems are categorized into either photovoltaic or thermal systems, concepts for solving the potential problems can be conceptualized. The photovoltaics are sensitive to individual cell failures in the strings of solar cells. This problem can be overcome by paralleling the strings and with diode shunting. This results in an equivalent maintenance load of about five to ten man-hours/hour for annealing or array addition to make up the loss.

The thermal systems may be vulnerable to NaK system reliability problems, necessitating maintenance equivalent to about ten man-hours/hour for mechanical repairs and replacement. Other solutions could be an intensive technology advancement effort to increase the reliability, or an innovative redesign to eliminate NaK.

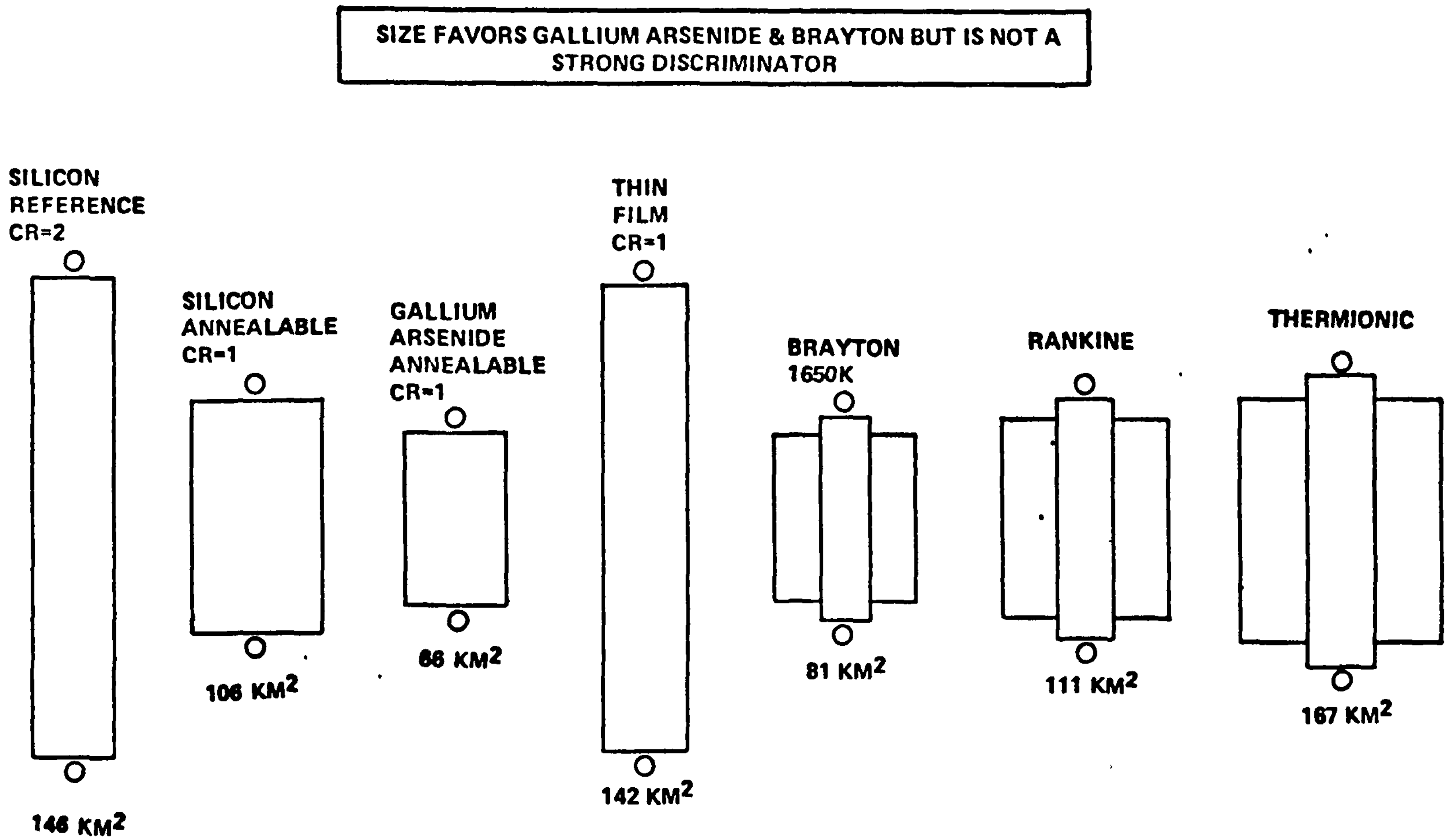

FIGURE IV-B-4 - SATELLITE SIZE COMPARISON

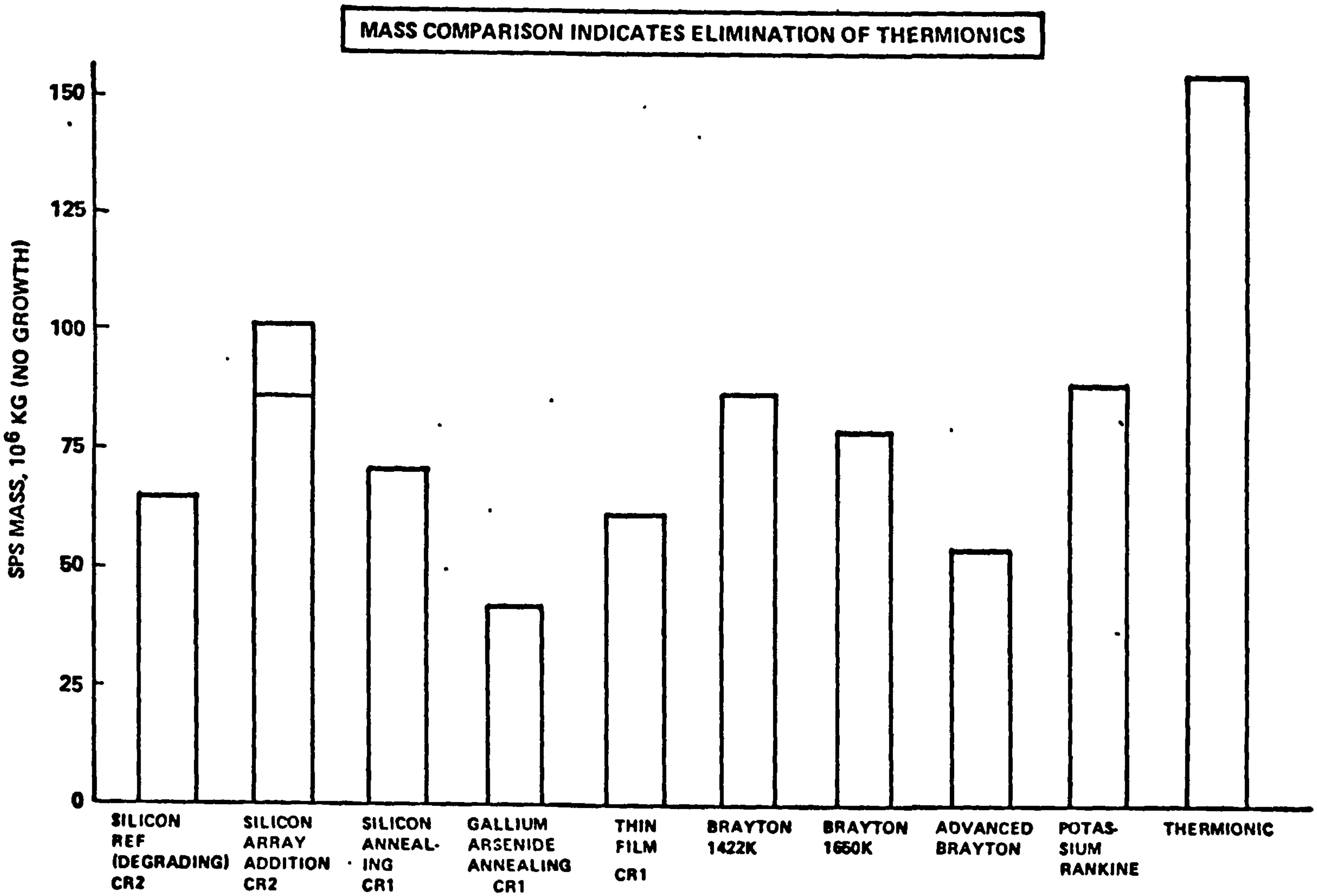

FIGURE IV-B-5 - SATELLITE TOTAL MASS COMPARISON (WITH NO MARGIN)

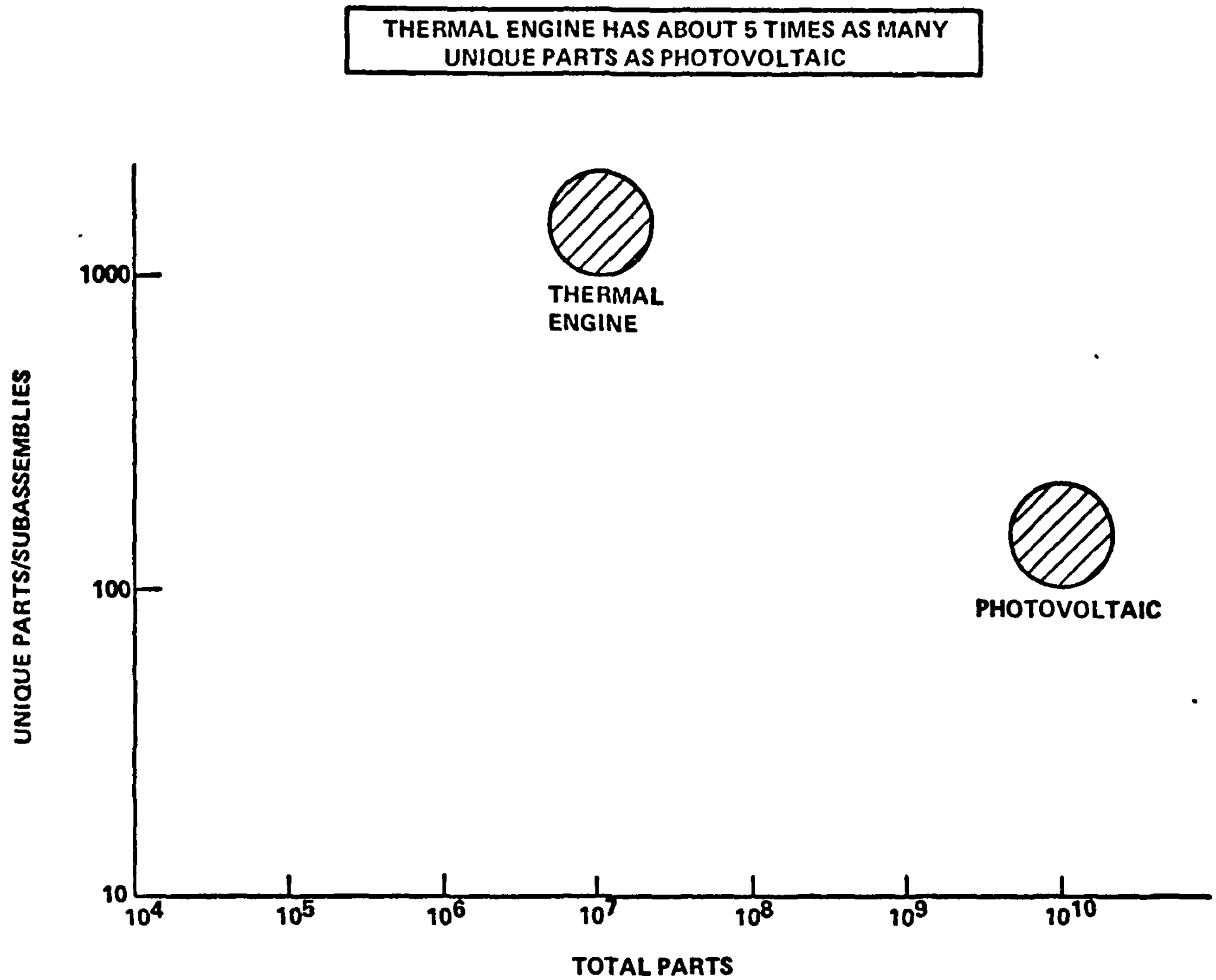

FIGURE IV-B-6 - SYSTEM COMPLEXITY COMPARISON

Construction Requirements - Figure IV-B-7 illustrates relative constructability of candidate concepts at LEO and GEO, and is based on a number of factors developed in the construction analysis. The length of the bars is a weighted, relative measure of constructability with a longer bar indicating a better rating, such as a combination of smaller construction crew size. The photovoltaic systems are easier to construct because they are less mechanically complex. Here can be seen one of the reasons for the desirability of no-concentration photovoltaic systems over those with concentration. The construction process is considerably less complex.

Transportation Requirements - Although there was no great difference in total launch mass between the best photovoltaic and thermal systems, the photovoltaics have a significant advantage in packaging density. Photovoltaic system components and materials can be packaged for launch to a density about 20 times that of the thermal systems. Some thermal engine components will barely fit into the reference launch vehicle payload dimensions. The average achievable packaging density was about 1300 Kg/m^2 ($81.16/ft^3$) for the photovoltaics and about 72 Kg/m^2 (4.5 lb/ft^3) for the thermal systems.

Technology Advancement Requirements - Table IV-B-1 lists those technology advancement requirements considered most significant. The Brayton thermal cycle and the silicon photovoltaic systems appear to have the least development risk with the Brayton being the most advanced. A continuous solar blanket manufacturing process would be more important to overall system cost than an increase in solar cell efficiency. For instance, a 14 percent solar cell manufactured with a continuous production process would make a silicon system very attractive, whereas an 18 percent cell made with today's processes would not allow an economically competitive system.

Environmental Effects Differential Factor - No serious environmental effects were found with any concept. The main factor is launch vehicle emissions which are not very significant and occur only in the launch year. Launch emissions are essentially proportional to SPS mass. A postulated accident with a fire on the launch pad presents some problem with gallium arsenide. There does not appear to be much of a toxicity problem, however, since analysis indicates that arsenic concentrations in any resulting smoke cloud would drop to allowable concentrations very quickly.

Materials Differential Factors - Gallium is the only material with a potential availability problem. Assumptions for recovery of gallium from various sources influence availability conclusions. Gallium today is recovered from the waste products of aluminum production, and processes are known which could improve the recovery process by a factor of 4. Alcoa has stated that more gallium could be recovered if more money was

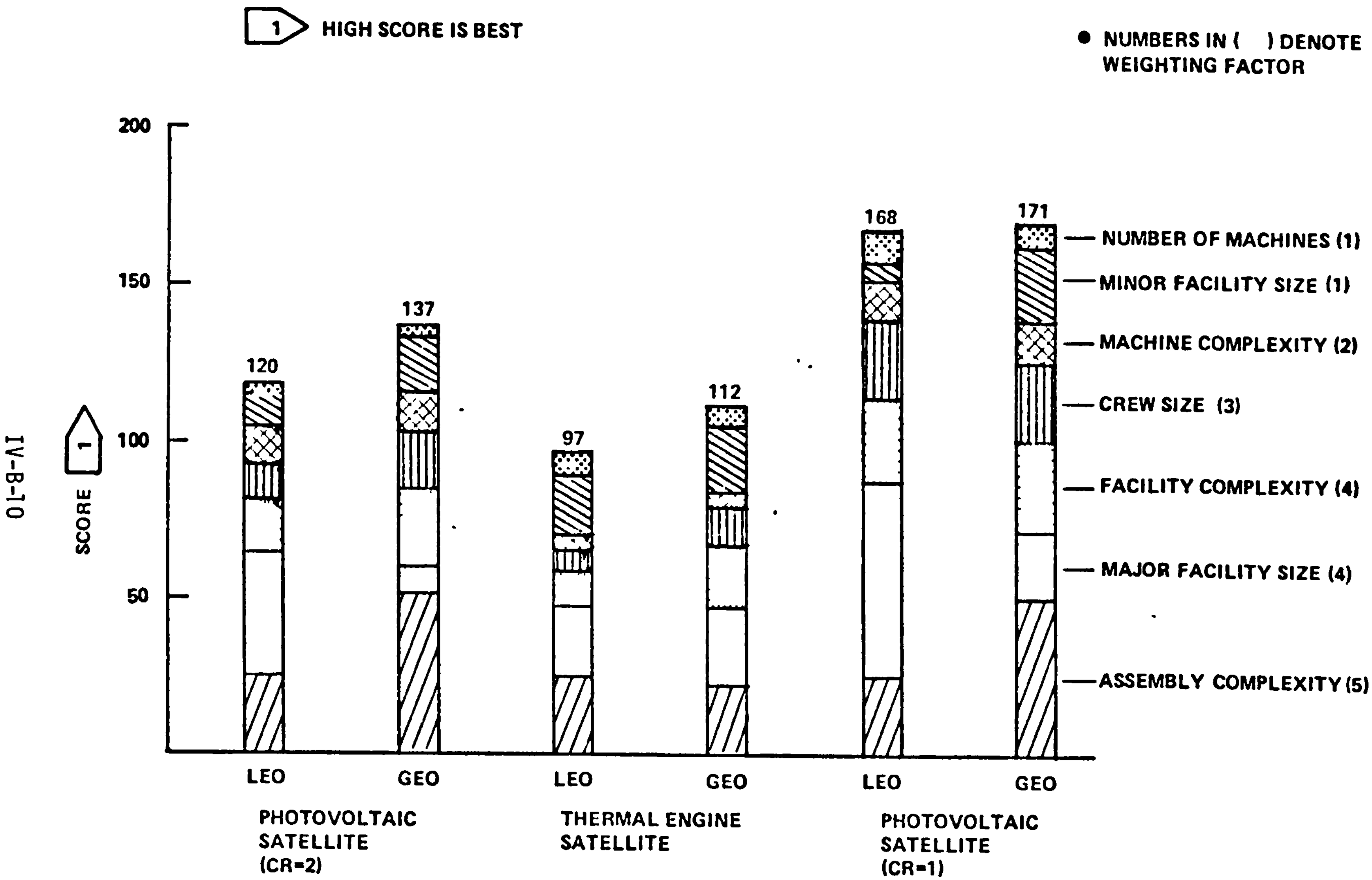

FIGURE IV-B-7 - RELATIVE CONSTRUCTABILITY RATINGS

PHOTOVOLTAIC			THERMAL CYCLE		
SILICON	GALLIUM ARSENIDE	THIN-FILM	BRAYTON	RANKINE	THERMIONICS
CONTINUOUS CELL/BLANKET PRODUCTION PROCESS — ANNEALING	THIN-FILM GALLIUM ARSENIDE APPLICATION PROCESS — CONTINUOUS CELL/BLANKET PRODUCTION PROCESS — ANNEALING	THIN-FILM TECHNOLOGY — PRODUCTION PROCESSES	RELIABLE FLUID CONTAINMENT	HIGH TEMPERATURE METAL VAPOR TECHNOLOGY — RELIABLE FLUID CONTAINMENT	THERMIONIC DIODE TECHNOLOGY

TABLE IV-B-1 - TECHNOLOGY ADVANCEMENT REQUIREMENTS

invested in recovery equipment. Production rate capability could be more of a limiter than total reserves. At the present time, availability of gallium does not eliminate the gallium arsenide system as a serious alternative concept.

Energy Conversion Evaluation Conclusions - Conclusions for this study are summarized on page IV-A-3. Detailed results and supporting analyses of the energy conversion evaluation may be found in the Boeing final report for Part I, published in June 1977.

IV. SATELLITE POWER STATION

B. SOLAR ENERGY COLLECTION SYSTEM

Harold E. Benson
Systems Evaluation Off.

1. Energy Conversion

b. Solar Cell Technology Status (Contracted Results)

A brief study effort of approximately 3 months has been conducted with the A. D. Little Corporation regarding solar cells. The objective of the study was to assess various solar cell materials and manufacturing methods to identify options which show greatest promise of leading to the development of a cost-effective SPS design. Underlying this objective is a tie-in between the current ERDA National Photovoltaic Conversion Program and requirements needed for a successful SPS solar cell program.

The prime goals of the ERDA solar cell program are to provide 500 megawatts of power per year, sell them at a price of less than $500 per peak kilowatt by 1986, and for the array efficiency to exceed 10 percent over an operating lifetime of at least 20 years. The primary focus is on reducing the cost of silicon solar cells by improving the manufacturing technology and by increasing production capacity.

SPS Requirements: For the SPS to produce a 5000 Mw output at the receiving antenna on Earth, its solar energy conversion subsystem will have to generate about 9000 Mw to allow for solar conversion and microwave transmission system inefficiencies. A production scenario in which 112 SPS's would be placed in operation by 2025 would require the deployment of up to 7 SPS's per year. Thus, the objectives of the ERDA National Photovoltaic Conversion Program, although supportive of SPS development goals, do not address the following production requirements of large photovoltaic arrays for the SPS:

- Low mass,
- High efficiency,
- Long life in the space environment,
- Ease of assembly,
- Capability of being transported to synchronous orbit, and
- Materials availability.

These requirements imply a diverging development effort for the SPS photovoltaic arrays, whose focus would be on thin-film solar cells, but in addition to single-crystal silicon would also include the development of the following photovoltaic materials:

- Amorphous silicon
- Cadmium sulfide, and
- Gallium arsenide.

Therefore, the cost projections which are being obtained in the Low Cost Silicon Solar Array (LSSA) project being carried out by JPL for ERDA are only

partially applicable to the definition of the most cost-effective photovoltaic arrays for the solar energy conversion subsystem of the SPS. The directly transferable development efforts in the LSSA project pertain to the production of semiconductor-grade silicon which presently has a market price of about \$65/kilogram. One of the objectives of the LSSA project is to develop processes for producing silicon which have been optimized for application to solar cells at high volume and low cost. The silicon production process which promises to meet the production goal of \$10/kg is based on the reduction of $SiCl_4$ by zinc in a fluidized-bed reactor. In addition, an objective of the LSSA project is to develop a number of methods potentially suitable for growing silicon crystals for solar cell manufactures; e.g., ribbon growth processes, such as edge-defined film fed growth; inverted Stepanov growth; laser zone ribbon growth; and web-dendritic growth. Among the ribbon growth processes the web-dendritic process appears to be very promising as a method of producing single-crystal silicon which could approach the mass and efficiency requirements of the SPS photovoltaic arrays. Sheet growth processes are also being investigated. Of these, the amorphous silicon method appears to be capable of producing thin-film solar cells with low mass. (The required silicon thickness is only about 1 μm).

Cost Projection Methods: Several methods can be used to project costs for silicon solar cells which have already reached an advanced development level and are gaining market acceptance: e.g., the design-to-cost concept, experience curve projection, and mature industry projection.

Design-To-Cost Projection: In this approach, portions of the total cost are allocated to the various process elements so that each process element can be tested against its individual cost goal. This permits key cost barriers to be identified and evaluated to point the way to required technical innovations to achieve cost reductions. The allocation of the total cost of the individual process elements relies primarily on engineering judgement and is influenced by known factors. For single-crystal silicon solar cell efficiencies in the range of 15 percent to 18 percent, the following design-to-cost allocations appear reasonable:

	$\$/m^2$ Range
Silicon Single Crystal	25 to 35
Junction Formation	10 to 15
Metallization	5 to 15
Anti-reflection	5 to 10
Array assembly	15 to 30
	60 to 100

The cost per unit area is a function of solar cell efficiency and the solar flux, which also is related to the cost per watt. For example, a cost goal of 50¢ per watt of 15 percent efficiency (AMO) translates into $\$100/m^2$, 30¢ per watt at 15 percent into $\$60/m^2$. An 18 percent efficient cell could be allocated $\$120/m^2$ to achieve a 50¢ per watt cost goal and $\$72/m^2$ for a 30¢

per watt cost goal. The costs for the substrate (1 mil Kaptron), cell interconnects (copper ribbon) and cover glass (10 µm glass resin) are allocated about $3/m^2, indicating that the major costs are associated with the silicon solar cell production.

Experience Curve Projection: Fig. IV-D-7A shows cost projections for silicon solar cell arrays based on the actual and projected experience with cost reductions as industry-accumulated volume grows. The experience curves relate the production volumes required to achieve projected costs. This approach is useful where marketing data for a number of years are available and where the growth of the market will not be strongly influenced by one application.

The substantial impact on industry-accumulated volume represented by the SPS means that experience curve projections must be used with caution. Furthermore, the assumption that there is a steadily growing market and that industry has the opportunity to make capital investments which can be amortized over a reasonable time span introduces additional uncertainties. At best, experience-curve projections are applicable to single-crystal silicon, since solar cells based on amorphous silicon, cadmium sulfide and gallium arsenide have not yet reached the stage where market factors determine costs.

Mature Industry Projection: The approach* which indicates how a mature industry relates materials output to costs represent a historical view of cost reduction. Photovoltaic materials of the type being considered for SPS may differ in their value-added components if government funding were to stimulate production of solar cells, as most likely would be the case in an SPS program development.

The various projections indicate that likely cost ranges for single-crystal silicon solar cells for the SPS photovoltaic arrays are:

50 - 70¢/Watt by 1985
15 - 25¢/Watt by 1995

Thin-Film Solar Cells: The attraction of thin-film solar cells, including amorphous silicon, cadmium sulfide, and gallium arsenide, is the potential for continuous mass production at a rapid production rate. Illustrative of the requirement to deploy 3 SPS's/year is an hourly production rate of 15,000 m^2 of photovoltaic arrays, assuming a 15 percent solar cell efficiency. This implies that if there is an installed manufacturing capability to produce photovoltaic arrays of 2-meter widths, about 50 machines would be required, at a linear manufacturing rate of 4 cm/sec. This manufacturing rate could be approached by automated processes being considered for thin-film

*Boeing SPS System Definition Study Presentation on May 6, 1977.

production, including spray techniques, vacuum-deposition techniques, and discharge techniques. For example, should it be desired to achieve the required manufacturing rate using an edge-defined film-fed ribbon process with a growth rate of 7.5 cm/min., assuming a 7.5-centimeter-wide ribbon, about 43,000 simultaneous ribbons would have to be grown and integrated with the photovoltaic array production lines.

Cost projections for thin-film solar cells are being developed, indicating the following cost goals:

Amorphous Silicon	-	15-30¢ per watt
Cadmium Sulfide	-	10-20¢ per watt

Gallium arsenide production processes are not yet well enough developed to permit reasonable goals to be established.

A. D. Little Conclusions

The ERDA National Photovoltaic Conversion Program, although furthering the photovoltaic materials and solar cell production technology, will not meet the development program objectives of the SPS. Valuable information and experimental data are being obtained which are useful for the SPS system and economic studies. However, the goals of the SPS development program are sufficiently different so that a dedicated photovoltaic development program will be required.

Considerations based on materials availability indicate that solar cells using silicon should be given the highest priority with cadmium representing a potential alternative material. Gallium arsenide solar cell applications may be limited because of gallium availability, unless low-cost processes to extract gallium from potential sources such as bauxite, flyash and oil residues are developed.

Single-crystal silicon will continue to be the leading candidate for photovoltaic arrays for the SPS because of significant production experience and an extensive data base.

A. D. Little Recommendations

- Perform R&D on candidate solar cells for SPS to achieve:
    - Low mass-per-unit area,
    - High efficiency,
    - High radiation resistance,
    - Capability of being packaged for subsequent deployment and assembly in orbit,
    - Capability of integration with extended lightweight structures, and
    - Capability of approaching initial performance with suitable processing (e.g., annealing) after prolonged exposure to the space environment.

- Define and develop processes for space manufacture of solar cells.

- Monitor on-going terrestrial cell material development programs, and select for in-depth evaluation and development those materials which are most promising for SPS.

- Establish an on-going orbital test program for flight testing of candidate solar cells, photovoltaic arrays, and structure-array integration methods on shuttle/spacelab missions.

- Establish an orbital program for flight testing of candidate photovoltaic arrays and assembly methods appropriate for the SPS.

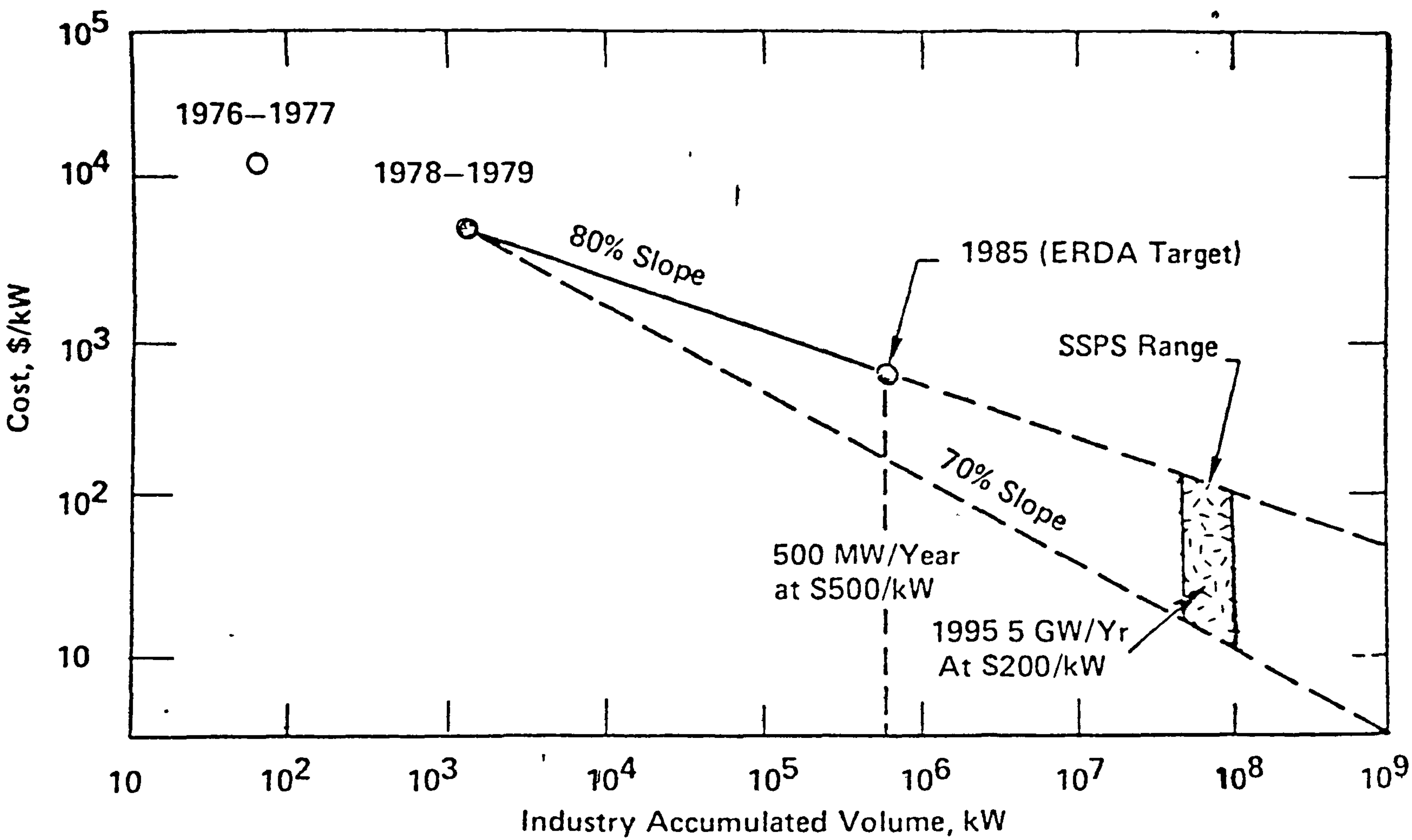

FIGURE IV-B-7A - COST PROJECTIONS FUR SILICON CELL ARRAYS

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IV-B-1-b. Solar Cell Technology Status. (In-house Assessment)

Over the past year, since the publication of the first JSC report on SPS activities, close contact has been maintained with those active in the development of solar cell technology both inside and outside of NASA. Considerable progress has been reported in areas of particular importance to SPS activities. Much work of interest is being performed with terrestrial solar power as the driving force; however, in most cases a form of the technology has applicability to SPS. The following is a summary of some of the highlights of the past year's work.

Single Crystal Silicon Cells---Work has been proceeding toward the fabrication of thin (50 micron) solar cells. The work, sponsored by JPL, involves the thinning of wafers sliced from large single crystals which start at conventional cell thickness and are subsequently etched to the 40 to 80 micron thickness. Though cells prepared in this manner will probably have little direct application for SPS, the high efficiency (11-12 percent) already achieved, and the low breakage loss from handling give credibility to the predicted utility of 50 micron thick cells in an SPS. Results from testing show lower degradation from radiation in the thin cells than from conventional cells. Figure IV-B-8 shows the relative power versus radiation dose level up to the levels predicted for an operational SPS. This factor could show weight savings in the use of thin solar cells beyond the basic mass per unit area difference even if the efficiency attained is below the 16-18 percent range. The impact of these recently reported results will be examined further over the coming year. Other activities aimed purely at improving solar cell efficiency have proceeded to the point where production cells can now be made available with efficiencies in the 14-15 percent range. In addition, progress has been made in the fabrication techniques for producing wraparound contact cells.

Silicon Ribbon Growth---Two programs are being funded to develop processes for continuous growth of single crystal silicon ribbons. The EFG (edge defined film fed growth) is producing large area material; however, the present process is such that impurities and defects in the crystal are limiting the quality of the cells. Though the process may produce material of sufficient quality for terrestrial solar cells, it may be unable to produce cells of the quality necessary for SPS application. The other process, dendritic web growth, is making good progress and has produced prototype production hardware which has been successfully operated. This process has shown the capability of growing webs of uniform thickness in the 100 to 300 micron range through control of the rate at which the web is drawn from the melt. Past work on this process has shown the ability to produce high quality ribbons from which high quality solar cells can be made. The dendritic web growth process

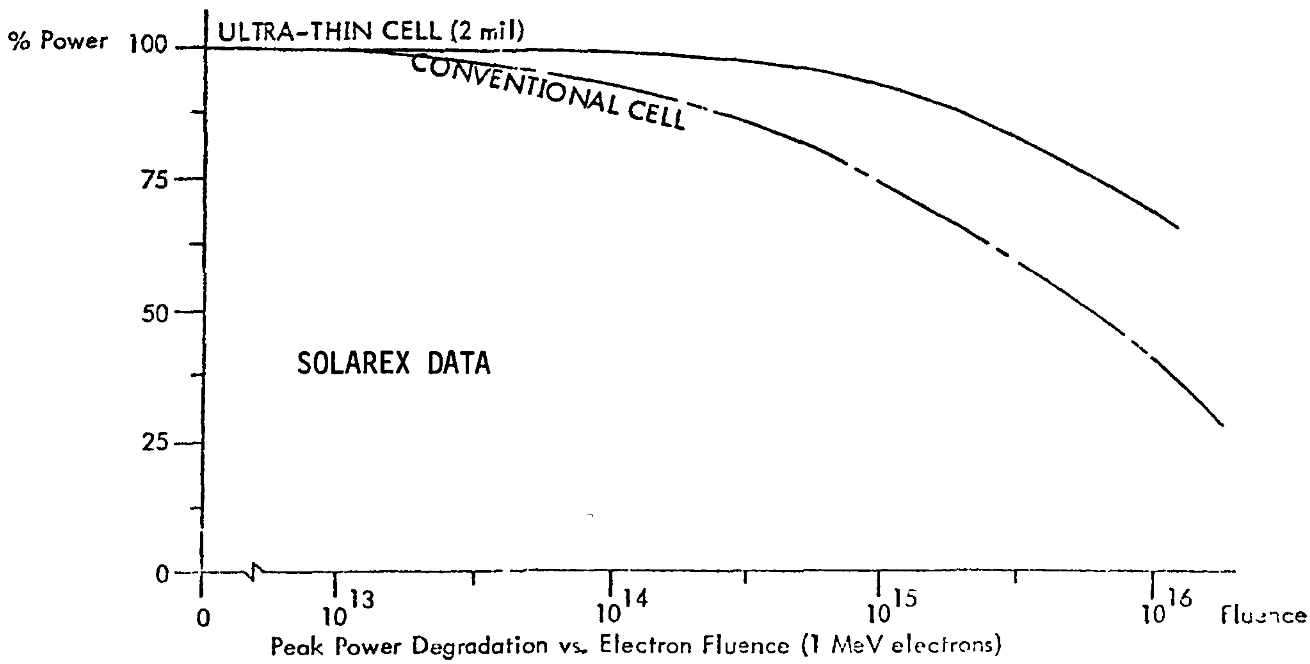

% Power
100
75
50
25
0
ULTRA-THIN CELL (2 mil)
CONVENTIONAL CELL
SOLAREX DATA
0
10^{13}
10^{14}
10^{15}
10^{16}
Peak Power Degradation vs. Electron Fluence (1 MeV electrons)

Figure IV-B-8

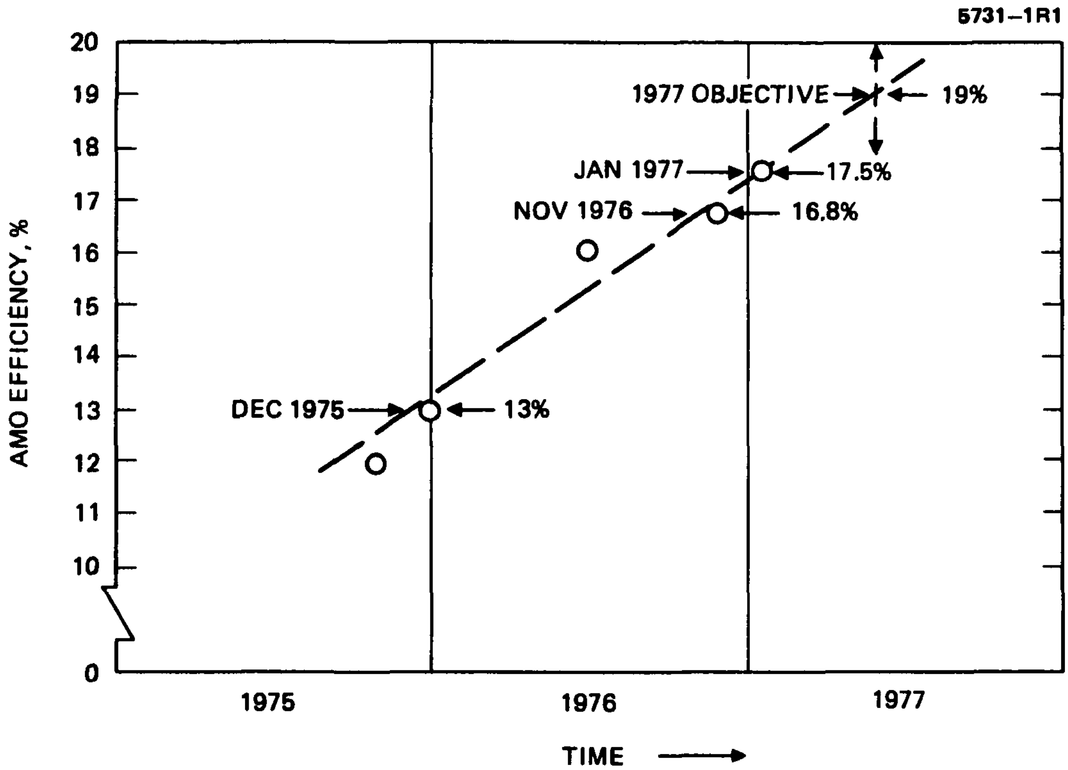
shows strong promise to produce high volume cells of a quality suitable for SPS use. It may be possible to combine the web process growing 100 micron thick blanks with the etch thinning process of Solarex to provide low cost thin single crystal silicon solar cells for SPS use.

Noncrystalline Silicon Cells---The most dramatic improvement in solar cell technology over the past year has been in the field of non-crystalline silicon solar cells. Investigators in the U.S. and Europe have produced solar cells from polycrystalline material which exhibits AM1 efficiencies in the 10-12 percent range. There are several characteristics about polycrystalline silicon solar cells which make them preferable to single crystalline cells. First, the manufacturing process is more nearly direct from molten silicon to a layer of material ready to have final processing into a solar cell and is thus inherently less costly to manufacture. Second, they can be readily manufactured in any convenient size and the thickness required is normally less than single crystalline. Third, polycrystalline cells show a high tolerance to impurities in the silicon. This is even shown in the "high" efficiency cells produced over the past year. Thus, the need for "hyperpure" silicon does not apply and the inexpensive metallurgical grade silicon is used. Early efforts to produce polycrystalline cells were limited to low efficiency due to the inability to deposit the silicon and achieve anything but small crystal grains (several microns in diameter); however, recent activities have been able to achieve large grain size (millimeters) with a high degree of order.

Another development in silicon cells is the recent publication of results in which solar cells have been produced from amorphous silicon and have achieved efficiencies in the 5-6 percent range. The researchers feel that they will be able to ultimately produce amorphous silicon cells with efficiencies of 14 percent. All the positive attributes associated with polycrystalline silicon cells apply to amorphous silicon cells except that amorphous silicon cells should be cheaper to produce.

Gallium Arsenide Solar Cells---Over the past few years an ever-expanding number of organizations have begun investigations into producing high efficiency GaAs solar cells. In almost all cases the new groups have made rapid progress to catch up with those already in the field. Today several organizations are producing GaAs cells with efficiencies in excess of 15-16 percent with the highest reported being 19 percent. The activity at Hughes Research Laboratories is in many ways typical of the rapid progress being made. A major difference is that Hughes has concentrated its activities on cells sized typical of conventional silicon cells; i.e., 2 x 2 cm. Figure IV-B-9 is a plot of the chronology of progress at Hughes and their near-term objective.

The high efficiency devices being produced consist of very thin active layers (10 micron) on a GaAs substrate which is on the order of



. Hughes Research Laboratories GaAlAs/GaAs solar cell efficiency.

Figure IV-B-9

200 microns thick. To become an attractive candidate for SPS use, GaAs cells must use Gallium only in the thin active layer. Work is going on to find other suitable substrates on which to grow or lay active GaAs layers. Thus far no high efficiency devices have been produced by this method.

Cadmium Sulfide Cells---Considerable activity is seen in the development of cadmium sulfide solar cells. The emphasis of this work is nearly exclusively for terrestrial use. Recent advances in this country and in Europe have enabled the fabrication of cells approaching 8 percent efficiency. Cadmium sulfide and others in the family of similar thin film devices are extremely interesting to consider for use in an SPS since by their nature they are lightweight, low cost devices. However, unless such a device can be fabricated with efficiencies in region of 11-14 percent, the assembly and transportation costs will offset these advantages.

IV-B-1-c. Solar Array Design Analysis.

The solar array work which was performed since the publication of JSC's first annual report on in-house SPS study activities has been significantly different in character than the first year's work. The solar array work in the first year concentrated on establishing a reference configuration which would provide a basis for whole system assessment from a variety of points of view; i.e., construction, transportation, economics, etc. In so doing, all elements involved in the JSC activity developed methods of analysis within their own area of interest. The first year laid a foundation which revealed many of the areas of sensitivity for SPS feasibility assessment. Major among these sensitive areas is the solar array which is the single largest mass and cost driver. Therefore, in this second year, solar array analyses have emphasized the study of areas in which either cost and/or blanket mass might be reduced.

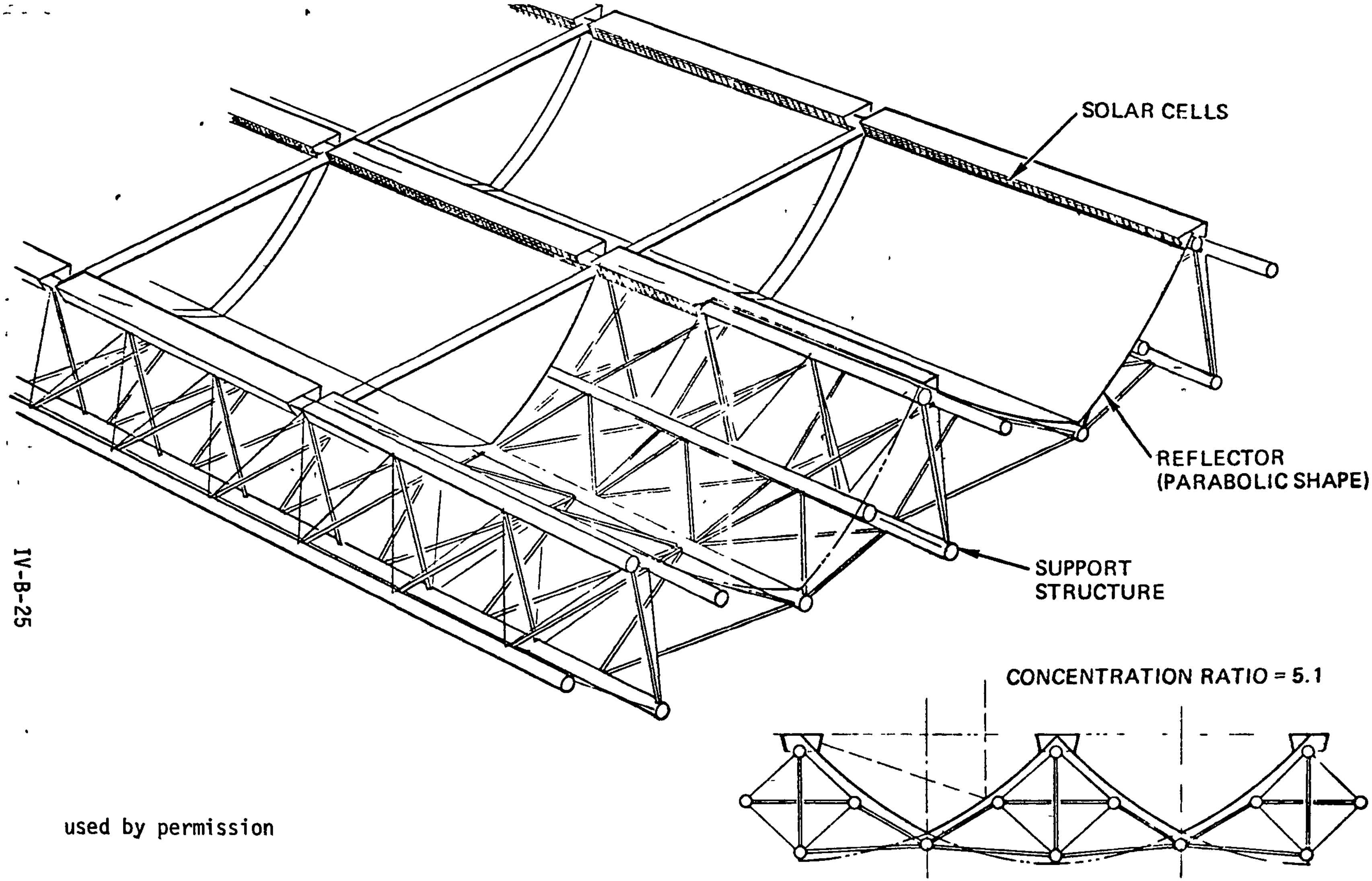
As can be seen from the discussion of solar cell technology, many significant advances have been made in the past year. Two major areas of investigation were pursued: (1) GaAs solar cells used in concentrated arrays (2X to 10X) and used in unconcentrated arrays, and (2) Thin film cells (e.g., polycrystalline silicon) with AMO efficiencies of 10 percent or greater.

These concepts were then compared with the reference system from the previous year. In the course of making the comparison, additional factors arise which influence relative "pros and cons" of the system concepts. With GaAs the availability and price of Gallium becomes a question (see Gallium availability section, this volume) and when using high concentration, the rate at which concentrator material degrades relative to solar arrays is a major concern.

Assessing the newly emerging "high" efficiency polycrystal silicon solar cell is hampered by the lack of data generated to date on temperature and radiation degradation coefficients.

GaAs Systems---To investigate concentrated GaAs systems the Rockwell concept of linear parabolic troughs was used as a basis (see figure IV-B-10). Figures IV-B-11 and IV-B-12 show temperature and blanket performance characteristics used. The analysis shows a very large weight benefit based on BOL (beginning of life) performance. The unsupported mass of the GaAs blanket and concentrator would reduce the mass relative the JSC 1976 reference by approximately 60 percent, but the system projected area would increase by 60 percent. Table IV-B-3 shows the assumptions upon which these results are based. The potentially large weight savings would be partially offset by the additional structure needed due to the significantly larger area of the system. The support of the reflectors in the linear parabolic trough configuration will require more structure to hold the shape of the concentrator and achieve the assumed 80 percent efficiency. In addition, the more highly distributed area will result in significantly higher distribution mass. Therefore, with

SKETCH OF SOLAR ARRAY
AT A 5:1 CONCENTRATION



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Rockwell International
Space Division

Figure IV-B-10

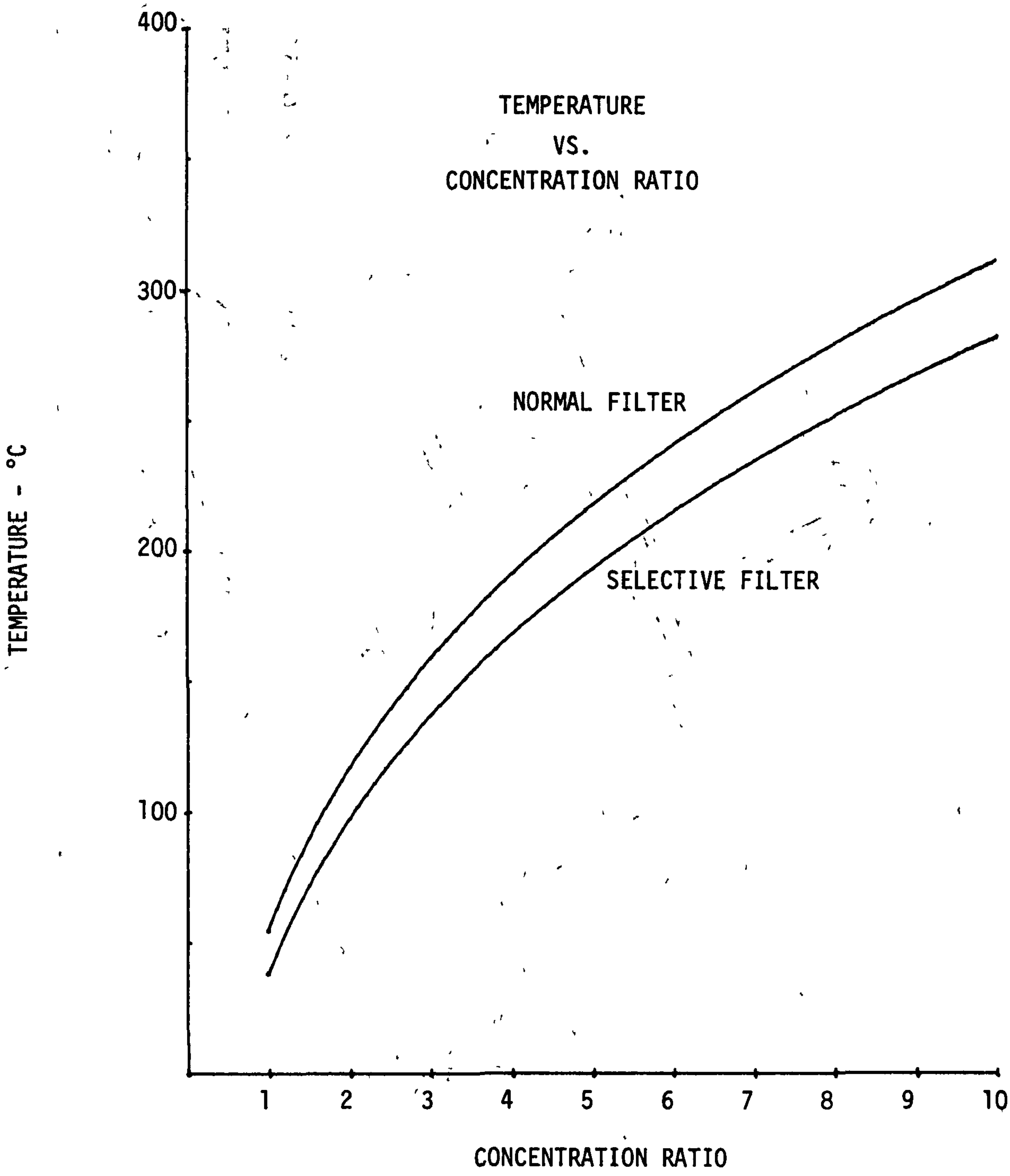

Figure IV-B-11

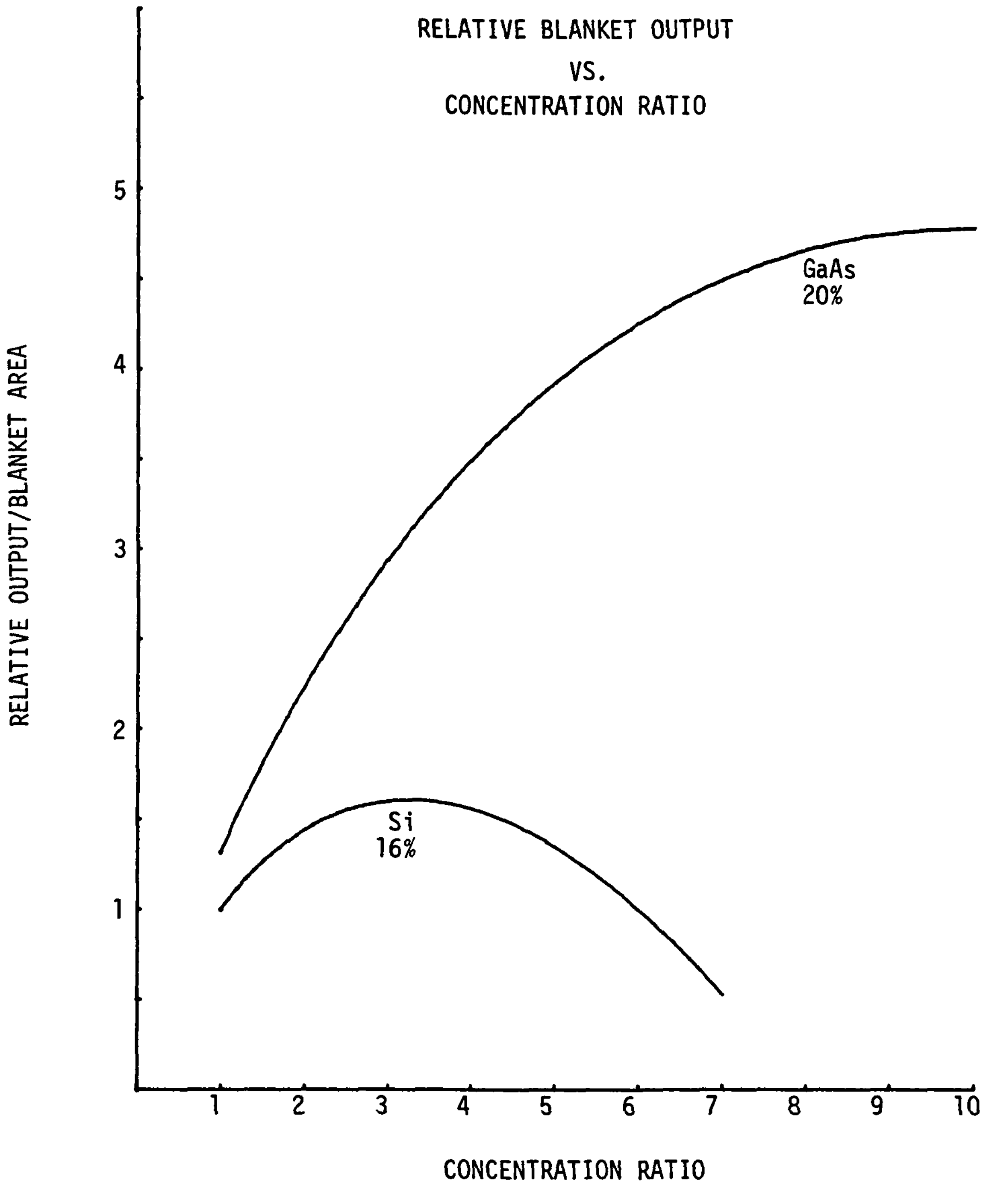

Figure IV-B-12

ASSUMPTIONS AND CHARACTERISTICS - GALLIUM ARSENIDE SYSTEMS

. Cell Efficiency	18-21% (AMO, 28^{o}C - 20% nom)
. Temperature Degradation	-0.25%/^{o}C
. Operating Temperature	10X con. 300^{o}C / unconcentrated 55^{o}C
. Concentrator Efficiency	80%
. Concentrator Degradation	40% (30 years GSO)
. Cell Thickness	25 microns
. Cover Thickness	25 microns
. Substrate Thickness	25 microns
. Interconnect (Al)	25 microns
. Radiation Degradation	15% (30 years GSO)
. Blanket Mass	328 gm/M^2
. Concentrator Mass	20 gm/M^2

OPERATING CHARACTERISTICS

Beginning of Life	Si(2:1 Ref)	GaAs(10:1)	GaAs(uncon.)
Area (planform)	7.34 M^2/Kw	14.2 M^2/Kw	4.0 M^2/Kw
Mass*	2.02 Kg/Kw	0.75 Kg/Kw	1.31 Kg/Kw
30 Year GSO			
Area (planform)	11.84 M^2/Kw	16.3 M^2/Kw	5.01 M^2/Kw
Mass*	3.26 Kg/Kw	0.86 Kg/Kw	1.65 Kg/Kw

* Mass is blanket and concentrator only, no supporting structure.

Table IV-B-3

the added structure and power distribution required due to the large area increase and the more stringent geometric precision of the reflectors, the whole of a 60 percent weight reduction would not be realized and would probably result in no more than a 30-40 percent reduction in mass. Table IV-B-3 contains the characteristics of the concentrated GaAs system. The degradation shown assumes uniform loss of reflectivity and makes no allowance for nonuniform illumination on the solar converter. Table IV-B-3 also contains performance characteristics of an unconcentrated GaAs system.

The use of GaAs solar cells in an unconcentrated array was at first thought to be an inappropriate concept due to the cost and availability of Gallium. However, the concept which was assessed shows that significant weight and area reductions over the silicon reference. The results shown for both GaAs concepts are predicated on the use of a very thin GaAs solar cell with an active GaAlAs layer of 10 microns or less (see GaAs discussion, Solar Cell Section). The effect of this assumption is to significantly reduce amounts of Gallium necessary to build a large number of operational SPS's.

Data which is currently available on degradation of GaAs solar cells suggests that the basic energy conversion element of the GaAs system will degrade no more than 15 percent over the 30-year life of an SPS. In fact, in the concentrated concept where the operational temperatures are between 200 and 300°C, a certain degree of damage annealing would occur continually which would reduce the expected degradation of the GaAs solar cells well below the 15 percent level. However, in the concentrated system the performance hinges on the characteristics of the reflector material. From the limited data which is available it appears that the reflective material will degrade by 40-50 percent over the 30-year lifetime of the system. The data further suggests that 20-30 percent degradation will be experienced during the first year or two of system operation.

The conclusions to be drawn from the preceding discussion are that under the assumed conditions, an unconcentrated GaAs array would allow the SPS array to be smaller, lighter, and over the 30-year operational lifetime of the system could be less expensive than the silicon array represented by the JSC reference system. The use of concentration up to 10X would enable a substantial weight savings. The much smaller area of active GaAs solar cells would result in less pressure from the Ga cost and availability issues. However, if the assumptions on reflector degradation are correct, the large investment (time and complexity) in the 10X concentration is hardly warranted since its efficacy wanes so rapidly.

Nonconcentrated Single Crystal Silicon---Following the publication of the JSC SPS first annual report, further investigation of degradation effects were undertaken. It then showed that the concentrator

degradation over a short period of time was considerably greater than was to be expected from the solar blankets. A study was then begun to take a more careful look at the relative impact on system performance due to degradation in the space environment. No consideration was given in this activity, to the degradation which might be suffered in a slow trip through the Van Allen belt which would be experienced during orbital transfer operations. Table IV-B-4 shows a list of the initially assumed characteristics which were used in the comparison. The results showed that the unconcentrated system would have a total area requirement approximately 30 percent less than the concentrated array which used the same cell, cover, and substrate assemblies. The weight of the unconcentrated array was 26-32 percent greater due to its requiring approximately 46 percent more active solar array blanket than the concentrated version. This first comparison showed that there exists a possibility of less overall cost associated with the unconcentrated concept than with the concentrated version from the first JSC reference.

The next step was to look into the reduction of system mass through lighter weight blanket. Table IV-B-4 also contains the characteristics of a "lightweight" blanket which has a mass per unit area of .35 kg/kw. The lighter weight evolves primarily from the use of a 50 micron cell but retains the 50 micron cover. When comparing this lightweight approach to the reference system the area relationships remain the same, but the unconcentrated system shows a weight advantage of 7 percent BOL and 12 percent 30 year. Thus, if the blanket cost can be kept the same as for the heavier version, a significant reduction in overall system cost will result. This cost reduction comes from (1) lower structure cost due to the significantly lower area to be built; (2) lower transportation cost due to the reduced mass; and (3) lower operational costs due to the less stringent orientation constraints which result from a planar array.

Polycrystalline Silicon Systems---From the section of this report on solar cell status, it is readily seen that the recent advances in polycrystalline silicon and amorphous silicon devices offer hope for achieving not only low cost and lightweight solar arrays, but a potential of combining these desirable attributes with reasonably high efficiency. Based on these recently published results from U.S. and European researchers, an assessment was made of the impact these cell types could have on an SPS. For the purpose of this study it was assumed that the radiation degradation and temperature coefficient of the silicon devices would be the same as for single crystal silicon (though there is reason to believe they will be more tolerant to particulate radiation). Table IV-B-5 contains the characteristics assumed for cells and blankets. The results show that with a device with a specification efficiency of 12 percent, the satellite area would be 3-7 percent less than the reference but would cause an increase in blanket mass of from 4-9 percent. The major advantage to be accrued from a concept of polycrystalline silicon or any thin film device is the potential to achieve \$100/kw costs; i.e., approximately 20-30 percent of the reference system cost for blankets and concentrators. Thus, if

CHARACTERISTICS SUMMARY - SINGLE CRYSTAL SILICON SYSTEMS

	JSC REFERENCE (2:1 con)	LIGHTWEIGHT (unconcentrated)
. Cell Efficiency	16%	same
. Temperature Degradation	$-0.45\%/^{o}C$	same
. Operating Temperature	$100^{o}C$	$55^{o}C$
. Concentrator Efficiency	80%	n/a
. Concentrator Degradation	40%(30 year GSO)	n/a
. Cell Thickness	100 micron	50 micron
. Cover Thickness	50 micron	50 micron
. Substrate Thickness	50 micron	25 micron
. Interconnect	25 micron (Cu)	25 micron (Al)
. Radiation Degradation	35% (30 year GSO)	17% (30 year GSO)
. Blanket Mass	$499\ gm/M^2$	$350\ gm/M^2$
. Concentrator Mass	$40\ gm/M^2$	n/a

OPERATING CHARACTERISTICS

	JSC REFERENCE	LIGHTWEIGHT
. BEGINNING OF LIFE		
Area (planform)	$7.34\ M^2/Kw$	$5.62\ M^2/Kw$
Mass*	2.02 Kg/Kw	1.97 Kg/Kw
. 30 YEAR GSO		
Area (planform)	$11.84\ M^2/Kw$	$6.61\ M^2/Kw$
Mass*	3.26 Kg/Kw	2.31 Kg/Kw

* Mass is blanket and concentrator only, no supporting structure.

Table IV-B-4

CHARACTERISTICS SUMMARY - POLYCRYSTALLINE SILICON SYSTEM

. Cell Efficiency	12% (AMO, 28^{o}C)
. Temperature Degradation	-0.45%/^{o}C
. Operating Temperature	55^{o}C
. Cell Thickness	50 microns
. Cover Thickness	50 microns
. Substrate Thickness	25 microns
. Interconnect	25 microns (Al)
. Radiation Degradation	35% (30 years GSO)
. Blanket Mass	310 gm/M^2

OPERATING CHARACTERISTICS

. BEGINNING OF LIFE

Area (planform)	7.12 M^2/Kw
Mass*	2.21 Kg/Kw

. 30 YEARS GSO

Area (planform)	10.96 M^2/Kw
Mass*	3.40 Kg/Kw

* Mass is blanket mass only, no supporting structure.

Table IV-B-5

blanket/concentrator elements constitute 60 percent of the cost and weight of the whole SPS, a polycrystalline silicon design for an SPS would add less than 6 percent to the whole system weight, but would reduce the cost for the whole system by almost 50 percent.

Efficiency and Degradation Effects---Beyond the single point concepts discussed in the previous sections, an evaluation was made of the impact (relative and absolute) of varying levels of efficiency achievement in the basic solar cells which are now considered major candidates. The information gives blanket mass and area for designs based on beginning of life conditions and 30-year conditions. Values were normalized against the JSC reference with a 2:1 concentration solar array. Figures IV-B-13 and IV-B-14 show the relative mass and area versus efficiency. The efficiency plotted is not the operating level but rather the specification efficiency at room temperature conditions. The degradation does not make allowance for a trip through the Van Allen belt which is associated with the self-powered LEO to GEO transfer mode of operation. It also makes no allowance for annealing the cells to reduce damage. Figures IV-B-15 and IV-B-16 are plots of the actual area and mass values used and are given per nominal kilowatt.

Conclusions (Energy Conversion Concept Options)---From the preceding discussion the following conclusions can be drawn: (1) The use of concentrators with photovoltaic energy conversion introduces considerable additional complexity to an inherently simple system and the little data available at this time cast strong doubt on their long-term performance. Thus, before one can feel comfortable about concentrators fulfilling their primary role of reducing system cost and weight, a great deal of data needs to be generated not only on long-term performance but also on beginning of life conditions; (2) The potential of high efficiency coupled with low degradation over 30 years makes Gallium Arsenide photovoltaics a compelling option for consideration. If the problem of Gallium availability can be resolved, the performance benefits might offset the increased energy conversion costs which are to be expected from this type of system. This is an option which, at this time, must be refined; (3) The recent advances which have been achieved in polycrystalline silicon devices and the promise of a reasonably high efficiency amorphous silicon device, potentially change the whole balance of relative cost with an SPS system. The realization of low cost, lightweight devices of this type (or any thin film device) could be the key to the ultimate economic viability of an SPS program.

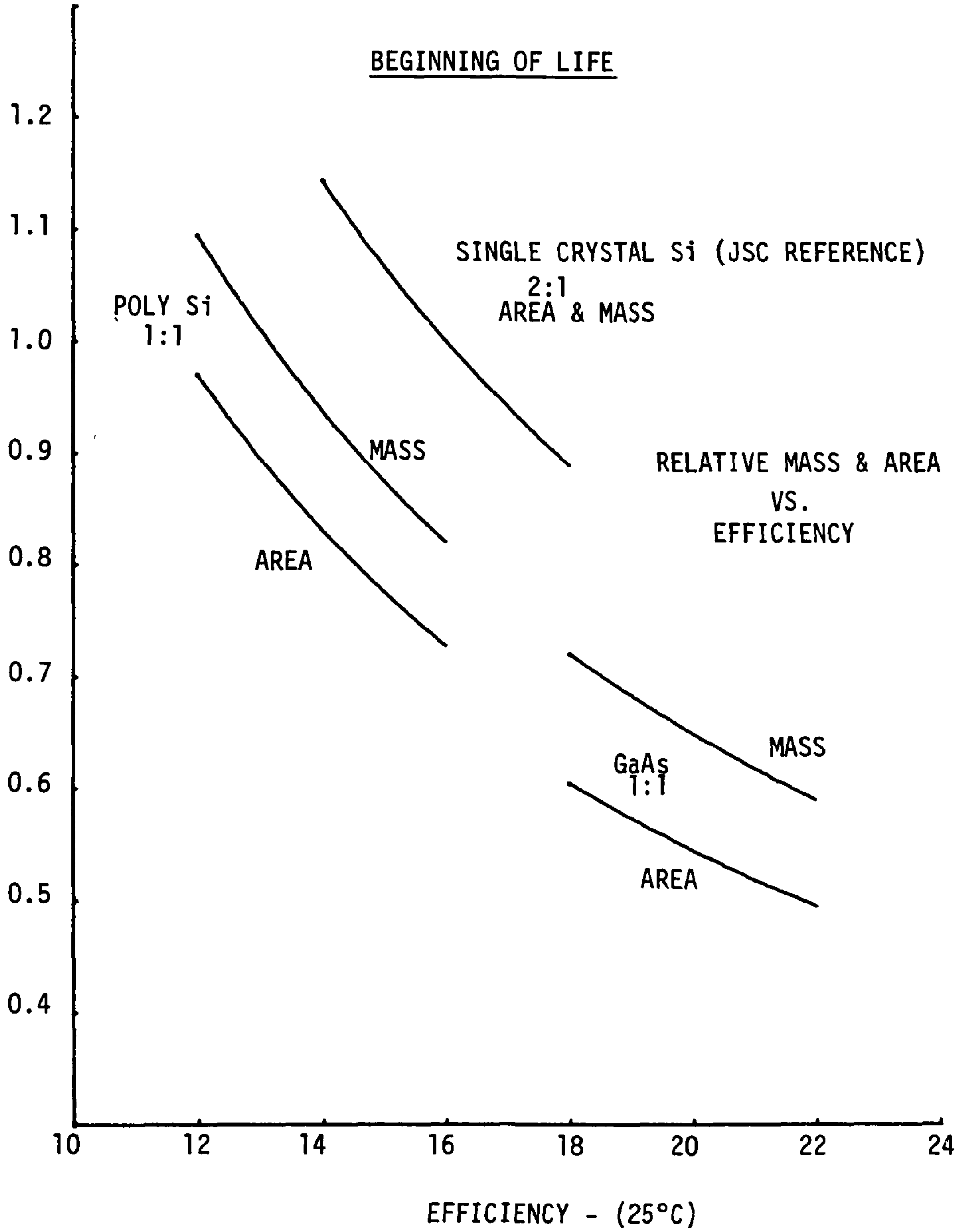
BEGINNING OF LIFE
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
SINGLE CRYSTAL Si (JSC REFERENCE)
2:1
AREA & MASS
POLY Si
1:1
MASS
AREA
RELATIVE MASS & AREA
VS.
EFFICIENCY
MASS
GaAs
1:1
AREA
10
12
14
16
18
20
22
24
EFFICIENCY - (25°C)

Table IV-B-13

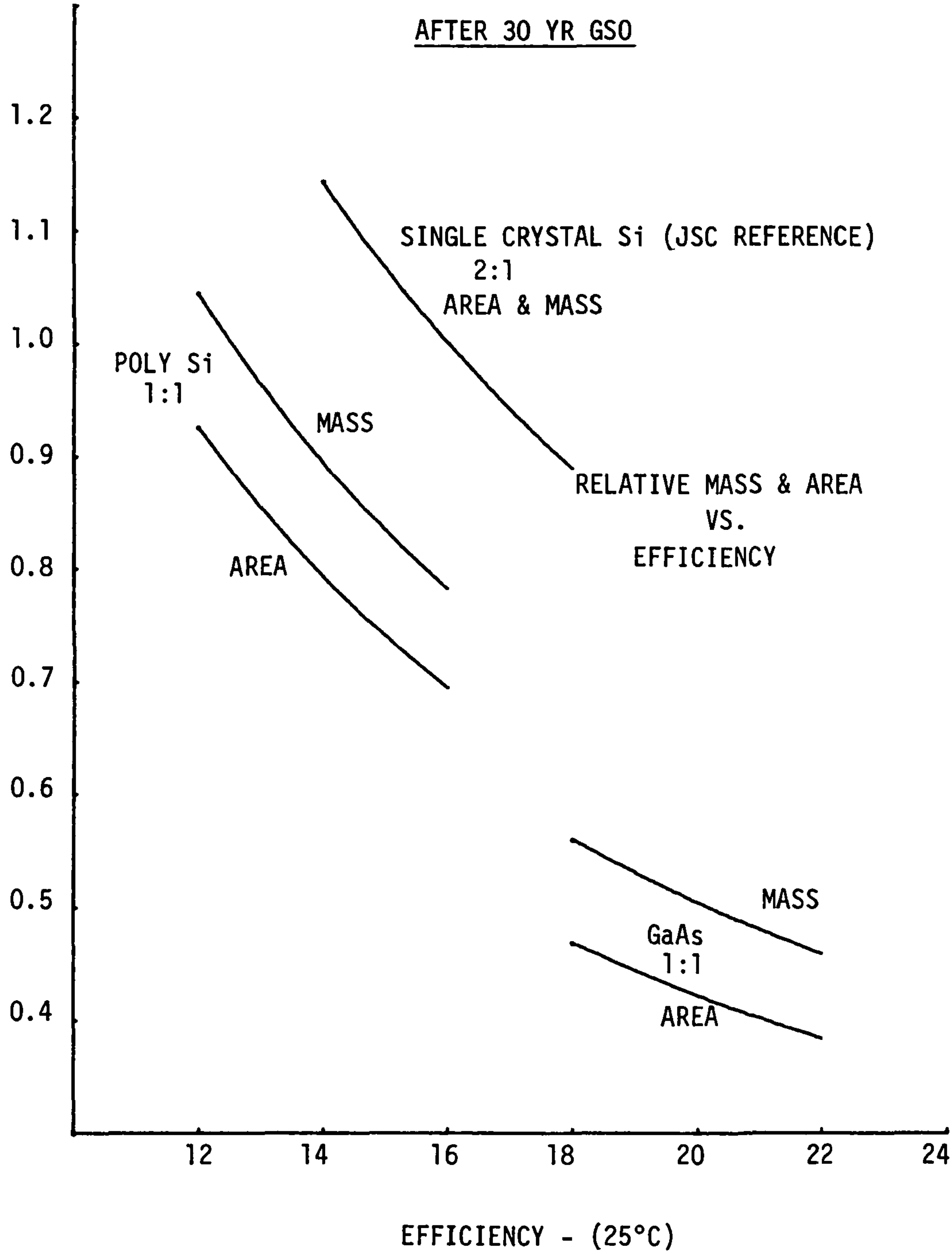
AFTER 30 YR GSO
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
SINGLE CRYSTAL Si (JSC REFERENCE)
2:1
AREA & MASS
POLY Si
1:1
MASS
AREA
RELATIVE MASS & AREA
VS.
EFFICIENCY
MASS
GaAs
1:1
AREA
12
14
16
18
20
22
24
EFFICIENCY - (25°C)

Table IV-B-14

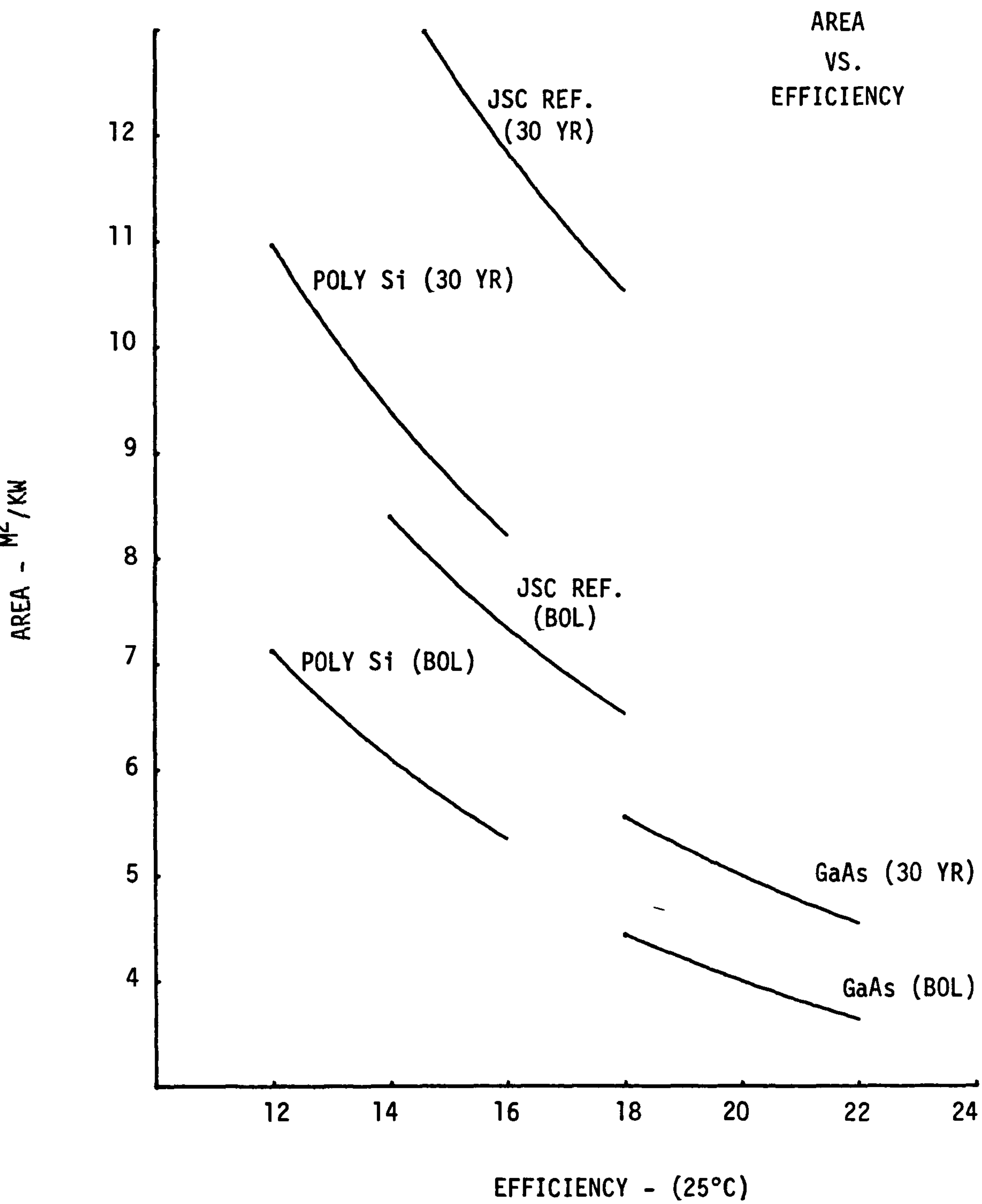

Figure IV-B-15

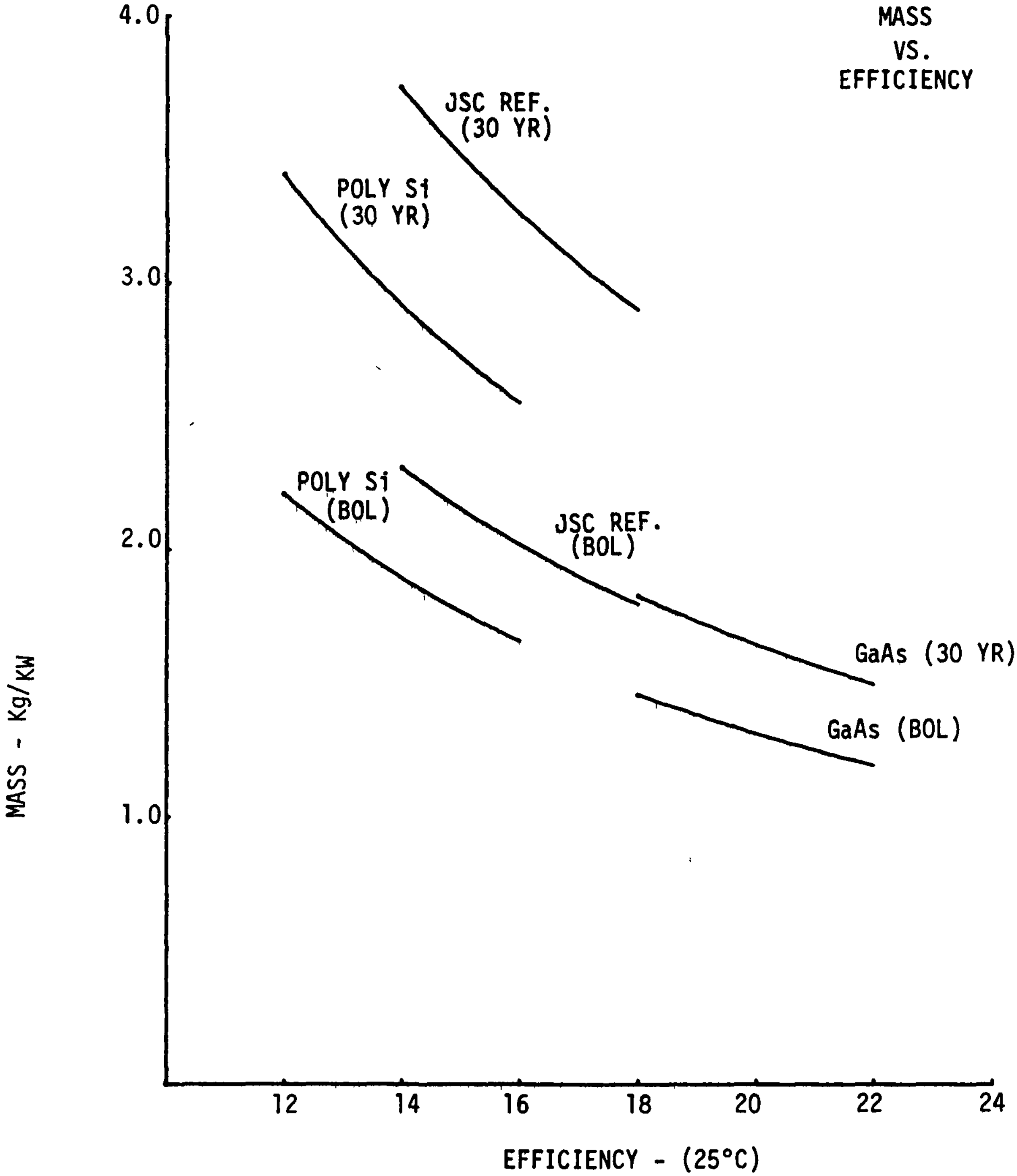

Figure IV-B-16

IV. SATELLITE POWER STATION

B. SOLAR ENERGY COLLECTION SYSTEM

2. High Voltage/Space Plasma Interaction

R. C. Kennedy
Control Systems
Development Div.

Introduction

Matter is generally considered to exist in three states: solid, liquid, or gas. The specific state is a function of the energy content and the state can be changed by the addition or removal of energy. If the energy addition is orders of magnitude above the level required for a change of the common states ionization occurs creating a substance composed of free electrons and free positive ions. When the number of charged particles is sufficient to establish the essential characterization of the substance (which remains electrically neutral as a whole) a fourth state of matter - the "plasma" - is said to exist. For example, while plasmas are generally associated with gaseous states, a plasma state can be observed in a solid such as a semi-conductor since it is characterized through the motion of electrons and holes in the substance (Ref. 1). In space, proton bombardment from the sun strips electrons from neutral atoms creating the plasmasphere and which in turm creates the concerns relative to the operation of high voltage systems in this charged particle environment.

The previous year's study activities recognized the two fundamental spacecraft/plasma interaction phenomena which could occur in geosynchronous orbit. Spacecraft charging, due to the so-called "magnetic substorms", is of concern to the SPS concept definition and is receiving considerable attention through a combined Department of Defense/NASA program. It is anticipated that solutions, or at least approaches to solutions, will be developed through this activity. The second, the interaction with the quiescent plasma, was not explored in any detail due to study priorities and in recognition of the (presumably) minimal severity of the problem at geostationary altitudes. However, with the advent of the concept of a low earth orbit (LEO) SPS test and demonstration article, the problem is greatly magnified because of the increased plasma density at the proposed operating altitudes (300-500 km).

This section will not attempt to present uniquely original material nor is it intended to reiterate all the various data, theories, and speculations concerning the problem. Rather, an overview assessment will be made as to how the interaction phenomenon may influence the formulation of the LEO test vehicle's power distribution and processing system. It should be recognized that this system represents a small, if not trivial, part of the overall problem when the solar arrays and RF

converter tubes are included as a part of the complete power system. However, many of the interaction effects, such as ion collection, insulator response, and arcing are common to the various power system elements. Toward this end the JSC Science and Application Directorate recently conducted a workshop which addressed the problem in general. It is anticipated that the published findings will treat the interaction phenomenon, as it impacts the solar arrays and RF converters, in some detail.

Discussion

The operational photovoltaic SPS will be electrically configured to operate at a nominal 20K VDC or 40K VDC for DC-RF conversion by amplitroms or klystrons respectively. From a power distribution point of view it is desirable to operate the LEO test article at the design voltage level for system weight efficiency. Using another approach, scaling work on a 1/15 scale structural similitude model recently completed by ES/Dr. R. Ried indicates that a 2700 VDC level (for the 40K VDC operational system) is preferred. While the voltage level requirements on the test configuration may vary an order of magnitude, the point to be recognized is that even the lowest level is more than an order of magnitude above what we have used in space--about 100 VDC.

When a potential is applied between different parts of a spacecraft - the conductor and return busses in this instance - the charge particles in the ambient plasma are attracted to the part of the vehicle with the opposite polarity (Figure IV-B-17). This current loop through the spacecraft represents a power loss with the magnitude a function of the applied potential. Insulation of the metallic conductors to minimize the current circulation would seemingly offer a straightforward approach; however, Reference 2 reports some interesting experimental results on insulators tested in a plasma environment. The electric fields generated by virtue of the applied voltage serve to attract the charged plasma particles to the insulator surface thereby greatly increasing the voltage gradient across the insulator. If high enough, the gradient will exceed the rupture strength and accelerate the reaction. Standard tests conducted on wiring insulator shows Kapton to have a dielectric strength of about 5000 volts/mil for normal spacecraft production wiring. Notch sensitivity tests on selected samples show an 85% reduction in strength when notched to two-thirds the material thickness. Any breakdown or damage that permits electrons to stream through the insulator will result in further erosion and damage to the material in the localized vicinity of the rupture.

An even more interesting phenomenon cited in the previous reference is the yet-to-be-explained dependency of the leakage current on the area of the insulation surrounding the hole. This phenomenon is referred to as a "funneling" effect wherein the insulator is conceived to play an active role in increasing the current flow orders of

magnitude over what would otherwise be the expected. Experimental data indicate that a pinhole surrounded by a 100 cm^2 area of Kapton would leak about 0.5 milliamps at a potential of +3000 volts in a plasma density of 2×10^4 electrons per cubic centimeter (Figure IV-B-18).

Before drawing inferences from these data, the specific array voltage levels need to be examined. Predictions of large leakage power losses from high voltage arrays are discussed in references 3 and 4. One example is cited wherein an array in LEO with 10% exposure of conductor (bare interconnects) would leak more power than the array can generate at a +16 KV level. The key here is that the assumption of a positive potential (electron collection) may not be rigorous since the array voltage will float to maintain compatibility with the environment. For example, a 20 KV array in LEO could stabilize to -15 KV and +5 KV (Figure IV-B-19). This means that the current flow, if it occurs, will be primarily from collection of the more massive slow-moving positive ions and any leakage current would be expected to be significantly reduced. The solar array voltage biasing aspect is discussed briefly in reference 5, and experimental data in reference 2 bears out the reduced leakage current for negatively biased electrodes (Figure IV-B-20).

Because of the presumed negative voltage bias across the array and the fact that the surface area of the power busses is small (even assuming flat-sheet conductors) compared to the array area, the relative power leakage from the distribution system will be of little significance even at high voltage levels. A more serious concern would be localized arcing to an adjacent part of the spacecraft at a different electrode potential. This possibility can be minimized by maintaining adequate separation between conductive paths and the use of additional insulation in areas with critical separation dimensions.

Finally, if the program decision is made not to configure the LEO test vehicle as a high voltage system, the power processing and distribution system could be mechanized to include a DC-DC converter to boost the collection voltage from a few hundred volts to the voltage level required by the DC-RF converters. Reference 6 indicates that such devices can be built at about 1 Kg/KW (2.2 lb/KW) for 100-watt converters. It is anticipated that converters up to 50 KW can be developed near this weight-to-power ratio and will operate at 95-97% efficiency.

Summary Remarks

The power processing and distribution system for the high voltage LEO test vehicle should not contribute significantly to power leakage to the ambient plasma. Arcing after damage to the insulator can occur and can be minimized through good design practices. Additional test and evaluation of candidate insulators is required and

should include an assessment of susceptibility to mechanical damage due to micrometeorite impacts and other types of hazards. Quality control on insulator production should be examined in an attempt to minimize or eliminate manufacturing imperfections.

If low voltage collectors are utilized a DC-DC converter can be developed for about 1 Kg/KW. It would be cost effective to standardize the voltage level (200-600 VDC) between the LEO test vehicle and the Space Station or Space Construction Base power system in order to maintain common power processing components and equipments.

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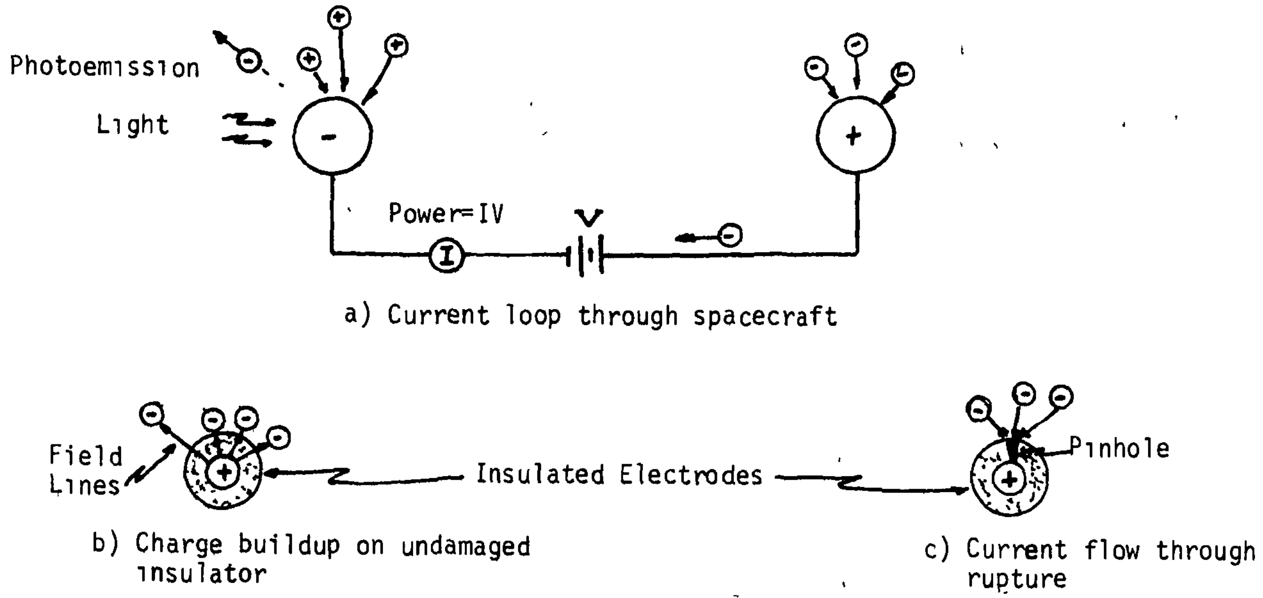


a) Current loop through spacecraft

b) Charge buildup on undamaged insulator

c) Current flow through rupture

FIGURE IV-B-17 - PLASMA INTERACTION EFFECTS (REF. 1)

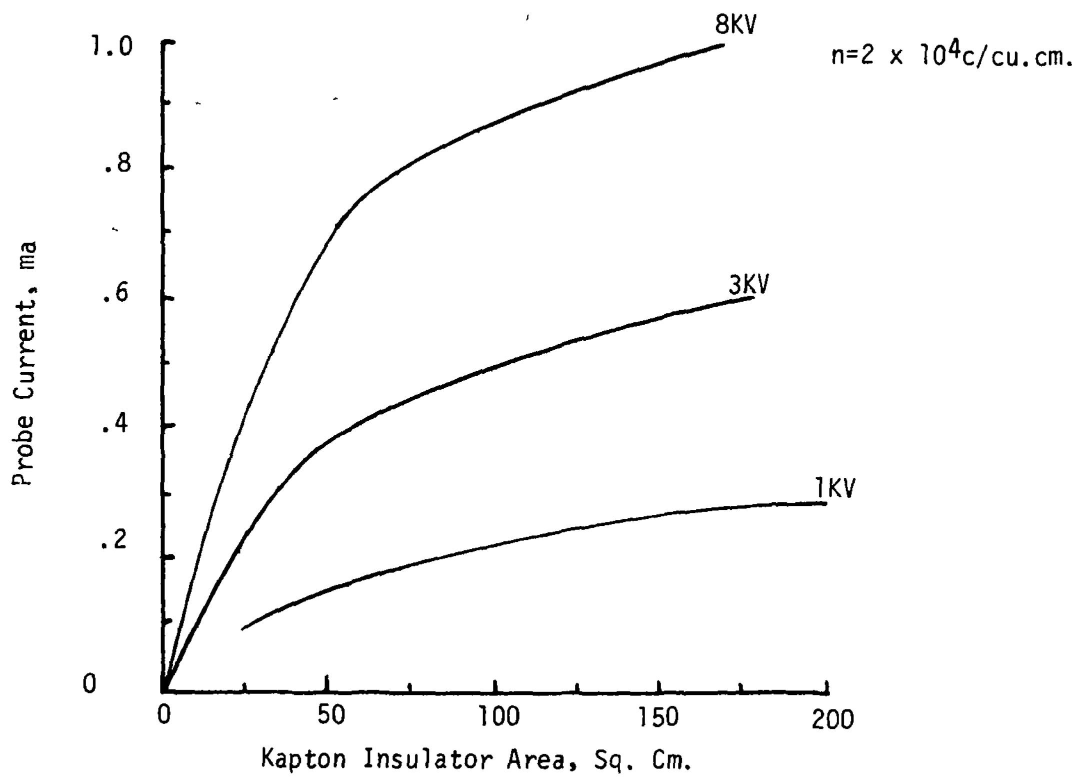
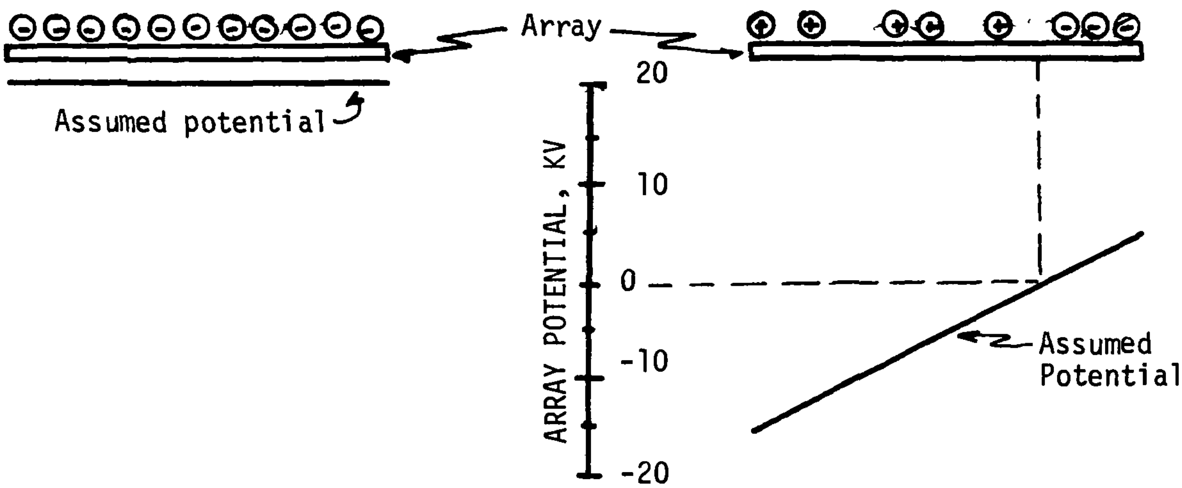


FIGURE IV-B-18 - INSULATOR FUNNELING EFFECT SURROUNDING PINHILE (REF. 2)



a) Constant Positive Voltage (Electron Collection)

b) Negative Bias Voltage (Low Collection)

FIGURE IV-B-19 - 20 KV ARRAY POTENTIAL MODELS (REF. 5)

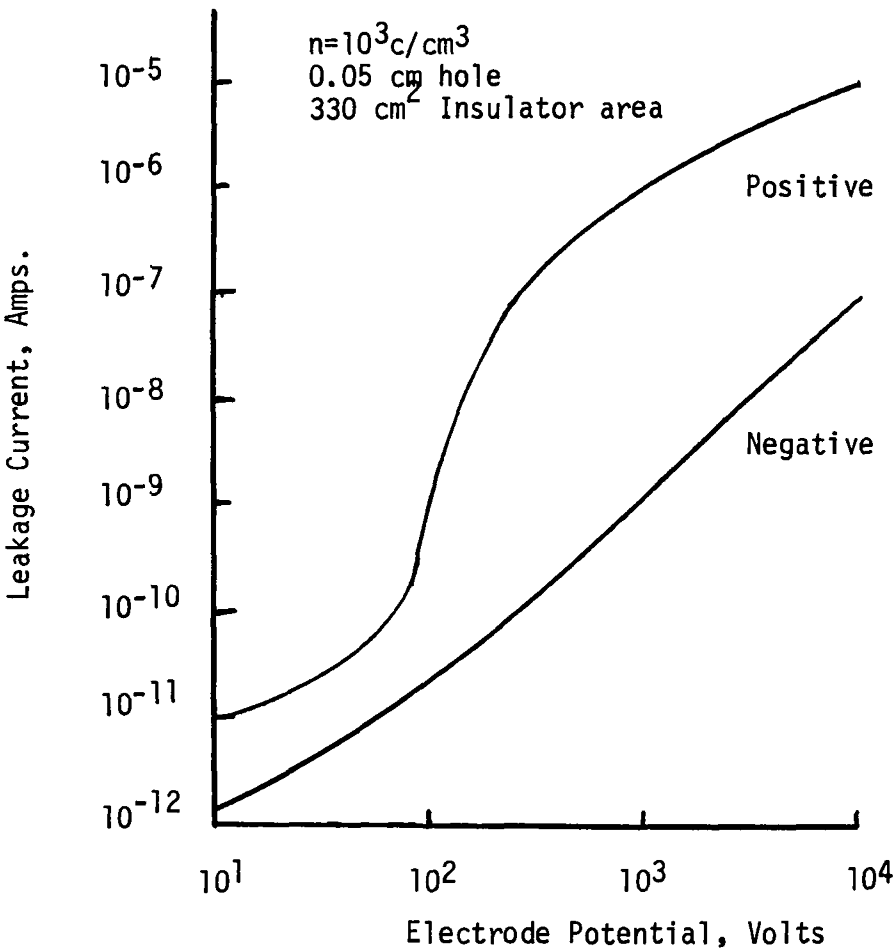


FIGURE IV-B-20 - EFFECT OF VOLTAGE BIAS ON LEAKAGE CURRENT (REF. 2)

T. J. Dunn
Structures and Mechanics Div.

A Candidate Structural Member

Introduction - Structural Requirements - Due to the impracticality of employing human labor for large scale construction in space, the fabrication of a gigantic structure must be amenable to automation of repetitive forming, placing, and attaching operations. If necessary, human labor might be used to join structural subassemblies with simple universal fittings but this is to be avoided if possible. The ratio of stiffness to material volume is much more important to the structural support of a solar power station than is the ratio of strength to material volume; therefore, both the material and the structural design should be selected to yield the least amount of mechanical and thermal distortion. And finally, the design should be selected by the total material and tooling weight as well as its packaged density.

Design Concept and Fabrication Approach - Figure IV-B-21 shows a test model of a structural member which can be constructed from coils of rods. This isotropic cylinder, whose surface consists of an open gridwork of equilateral triangles, is efficient in reacting axial, torsion, bending, or shear loadings and is uniquely configured to take full advantage of the orthotropic stiffness of uniaxially reinforced composite rods. The structure consists of a set of longitudinal rods attached to two sets of overwrapped helical rods which are wound in opposing helical directions. The longitudinal rods can be placed outside, inside, or between the helical rods. Since the rods can be joined by welding, the only debris problem occurs if the ends have to be trimmed. Unusually high length to radius of gyration ratios have been calculated for this type of structure.

Figure IV-B-22 shows a tooling concept which might be used to fabricate this structural member. The three sets of coiled rods are stored in freely rotating nested concentric containers which are attached to a powered tool consisting of three concentrically rotating rings which contain rod guides and feeding rollers. Automatic welding apparatus attached to the inner and outer rings weld the rods together as they emerge from the tool.

Test Results - The concept verification model shown in Figure IV-B-21 was made of 2017 aluminum alloy round wire and weighed three-fourths of a pound per foot. It failed under a compressive load of thirty-two hundred pounds.

Development Work Required - Material best suited for this structural concept is not available off-the-shelf because there has been no demand for it. Some development work will be necessary in the pultrusion process using graphite reinforced thermoplastic resin to obtain development quantities of rectangular rods of the desired sizes in unlimited lengths. It may be necessary to wind some of the graphite fibers to prevent the longitudinal fibers from separating under compressive loadings and to obtain a near zero coefficient of thermal expansion.

Joining techniques need to be developed to determine the fastest and most energy efficient method of welding the thermoplastic rods at their contiguous intersections. Ultrasonic, thermal, and electro-magnetic processes have been used on similar materials, but the best method for this application has not been established.

An automatic fabrication tool must be developed to demonstrate this concept and to produce test articles that fully represent the final product.

NASA
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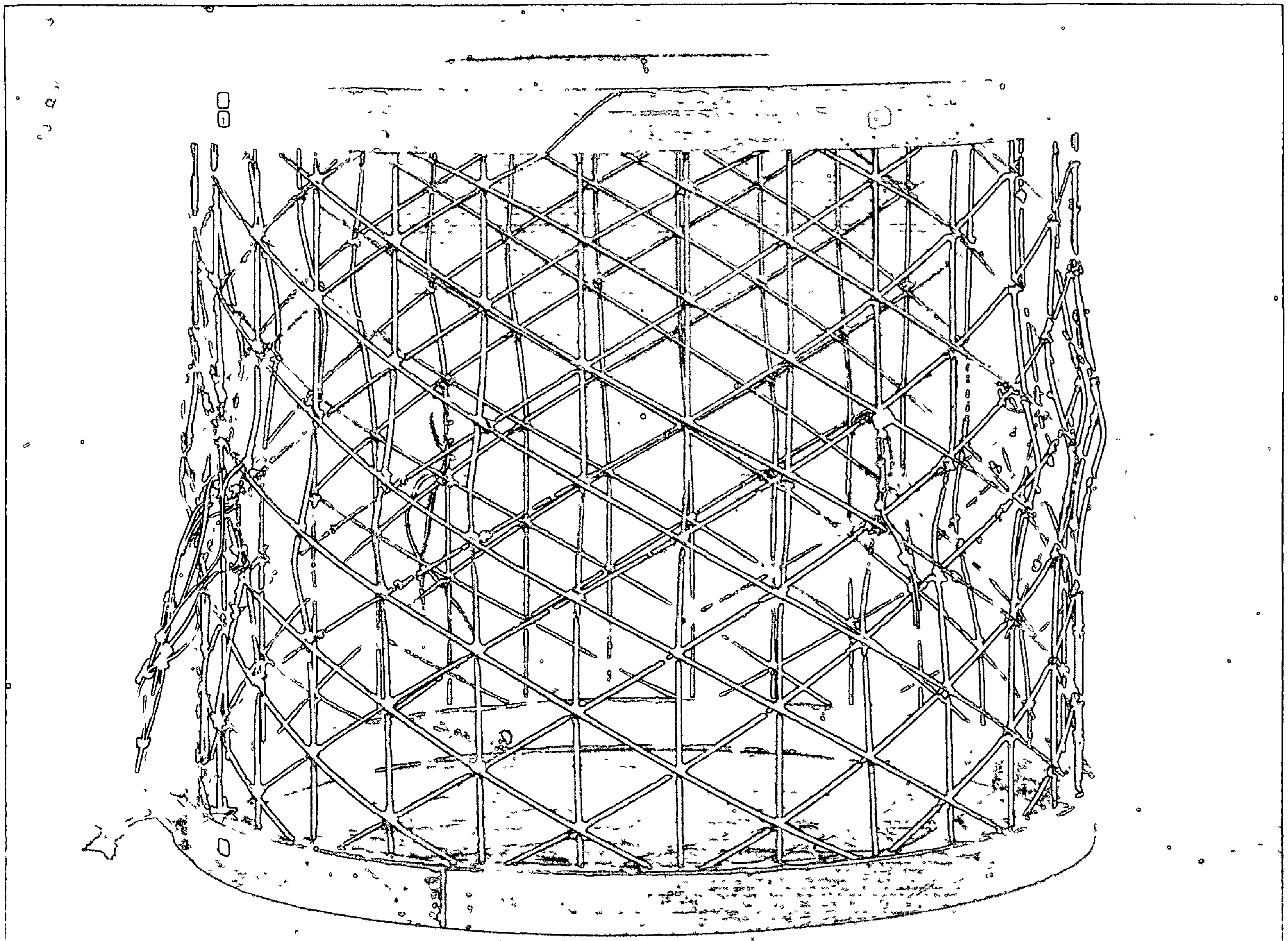

Figure IV-B-21 ISOGRID TEST ARTICLE

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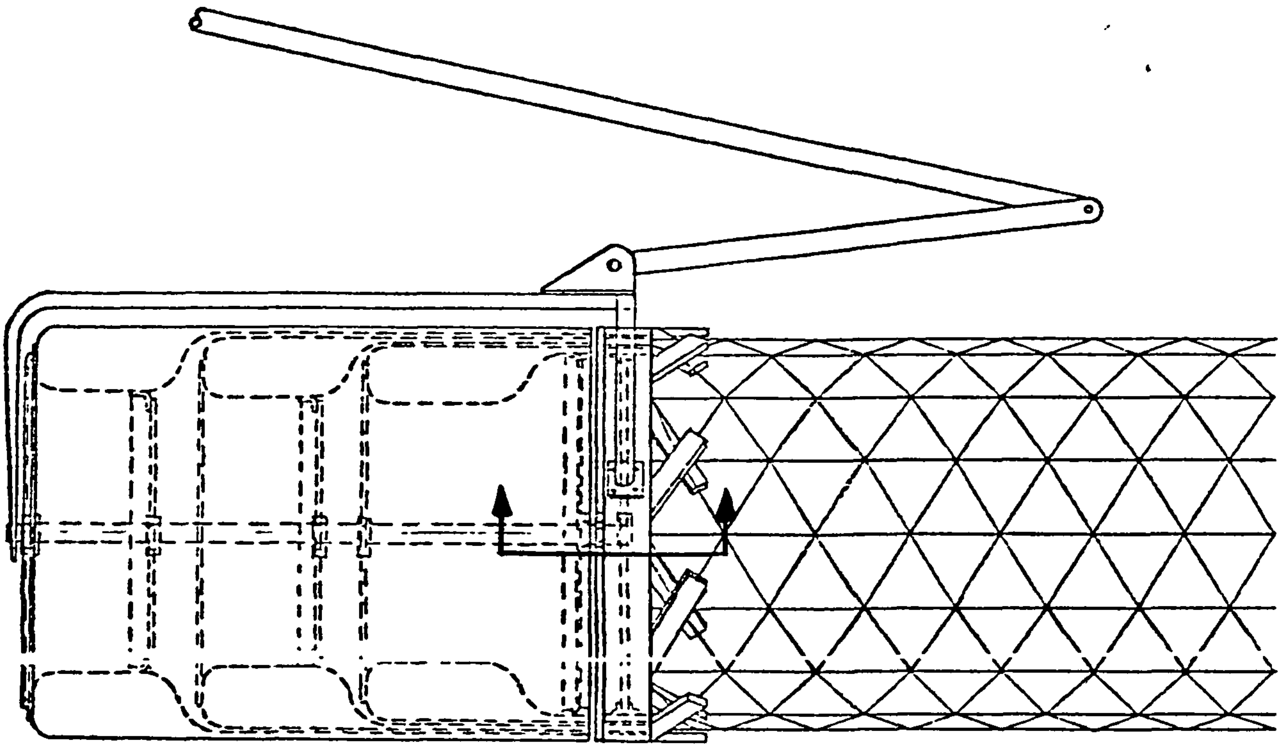
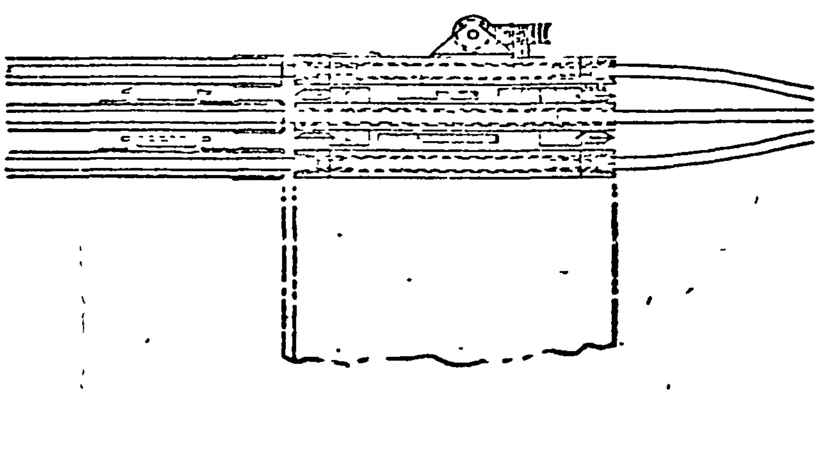
ORIGINAL PAGE IS POOR

Figure IV-B-22

ISOGRID CYLINDER FABRICATOR





IV.C. MICROWAVE POWER TRANSMISSION SYSTEM

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1. Microwave System Analysis

Introduction

The analysis tasks of the SPS microwave systems discussed in the 1976 JSC report "Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts - Volume II," were concerned mainly with system sizing and tradeoffs, definition of subsystem efficiencies, and development of performance requirements. As a result of those analyses, a 1 Km diameter, 5 GW antenna system was defined, employing a 10 dB, gaussian taper illumination across the array surface. An error budget with 10^{o} RMS phase error, $\pm$ 1 dB amplitude variation across each surface, and 2% failure rate for the DC-RF power converter tubes (klystrons or amplitrons) was developed.

The subsequent analysis tasks, as discussed in this second JSC report, investigate alternate options including (1) other antenna illumination functions, (2) smaller SPS system sizes (3) multiple transmit antenna (cluster concept) and (4) performance requirements for mechanical pointing of the transmit array. Based upon inhouse analyses and system studies by outside contractors it appears that the SPS microwave system can attain with greater certainty the required performance for efficient power transmission.

a. Antenna Illumination Functions

(1) Gaussian - The aperature distribution function across the transmit array should maximize the amount of RF power intercepted by the ground rectenna and minimize the sidelobe levels. The previous analysis (reference IV.C.1) had a truncated Gaussian taper of the form.

$$E_{(r)} = e^{-.115 \text{ dB} \left[r/r_o\right]^2} \qquad (1)$$

where dB - is the amount of taper from the center to the edge of the array.
r/r_o - is the normalized radial position across the circular transmit array.

which is a good approximation for an optimum aperature distribution. Considering the thermal limitations in the transmit array and the estimated power density limitations due to ionospheric interactions, a 10 dB Gaussian taper was selected which has an 88% collection effieiency at an rectenna radius of 5,125 meters. The power density

at the center of the rectenna is 22 mw/cm^2 for a 1 Km, 5 GW antenna system with the reference error parameters $\sigma = 10^o$, $\pm$ 1 dB and 2% failure rate. This performance data, as shown in figures IV.C.1 through IV.C.5 will be used to ascertain the relative performance of alternate antenna illumination functions.

Other illumination functions, specifically the cosine on a pedestal and the quadratic functions, operating in the presence of **phase** and amplitude errors and element failures, will now be examined. If the same error parameters, i.e., $\sigma = 10^o$, $\pm$ 1 dB, and 2% failures, are applied to these illumination functions, their relative performance can be obtained from collection efficiency curves and antenna pattern data.

These calculations are performed using a simulation program in which the electric field at each point on the ground is the sum of the individual radiation patterns from each of the 7,850 subarrays on the transmit antenna. The magnitude and phases of the electric fields at each point on the ground are evaluated and summed over a two dimensional region to determine the fractional power content relative to the total power transmitted. The percentage collection efficiency for the total antenna system will vary with collector area. For the SPS concept, only a portion of the main lobe will be collected; the sidelobe energy occupies a very large area at minimal density levels and is not economically feasible to collect.

(2) <u>Cosine on a Pedestal</u> - The cosine on a pedestal illumination may be represented, for a circular aperature, by

$$E_{(r)} = \cos^n \left[\theta \left(\frac{r}{r_o} \right) \right] + P$$

where n - is the exponent weighting factor
r/r_o - is the normalized radius
P - is the pedestal height

The collection efficiency curbes are shown in figure IV.C.1, for exponent weightings of 1/2, 1, and 2, pedestal heights of .5 and .8, and angles of 80^o and 90^o. For these calculations the 10m X 10m subarrays in the phased array have uniform phase and amplitude illumination across the transmitting surface. The errors in amplitude and phase are gaussian with mean square values of $\pm$1db and 10^o, respectively. The mean phase error is assumed zero.

The data indicates higher efficiencies are achieved with larger exponent weightings (n = 2) and $\theta = 90^0$. The next step in the analysis is to vary the pedestal height with n = 2 and $\theta = 90^o$ being held constant as shown in figure IV.C.2. The highest collection efficiency at a rectenna radius of 5125 meters is 87.95% for a pedestal height of .4.

Figure IV.C.1 -Collection Efficiency vs Various Cosine Tapers With Specified Parameters (σ = 10° ± 1 dB, 2%)

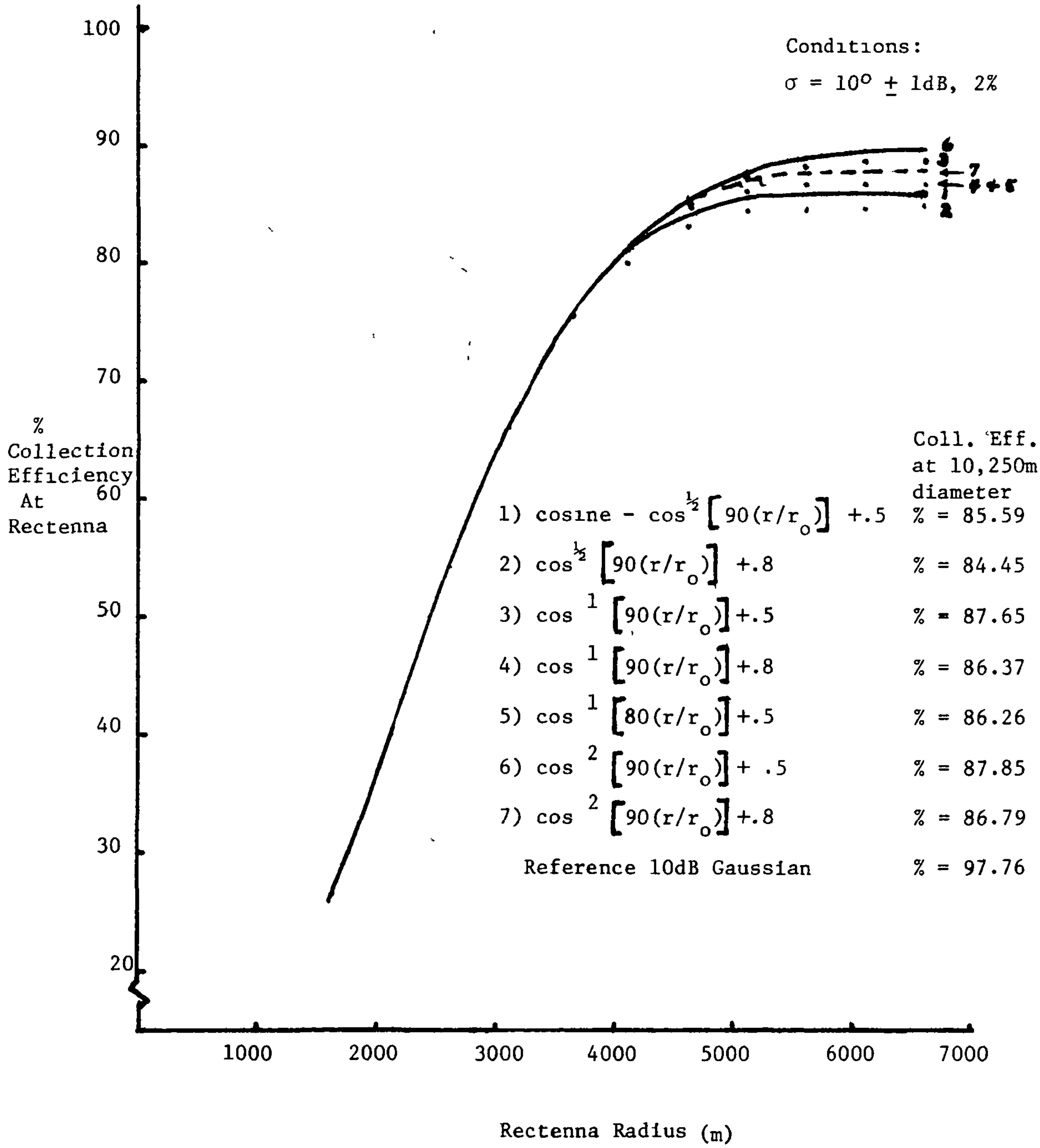
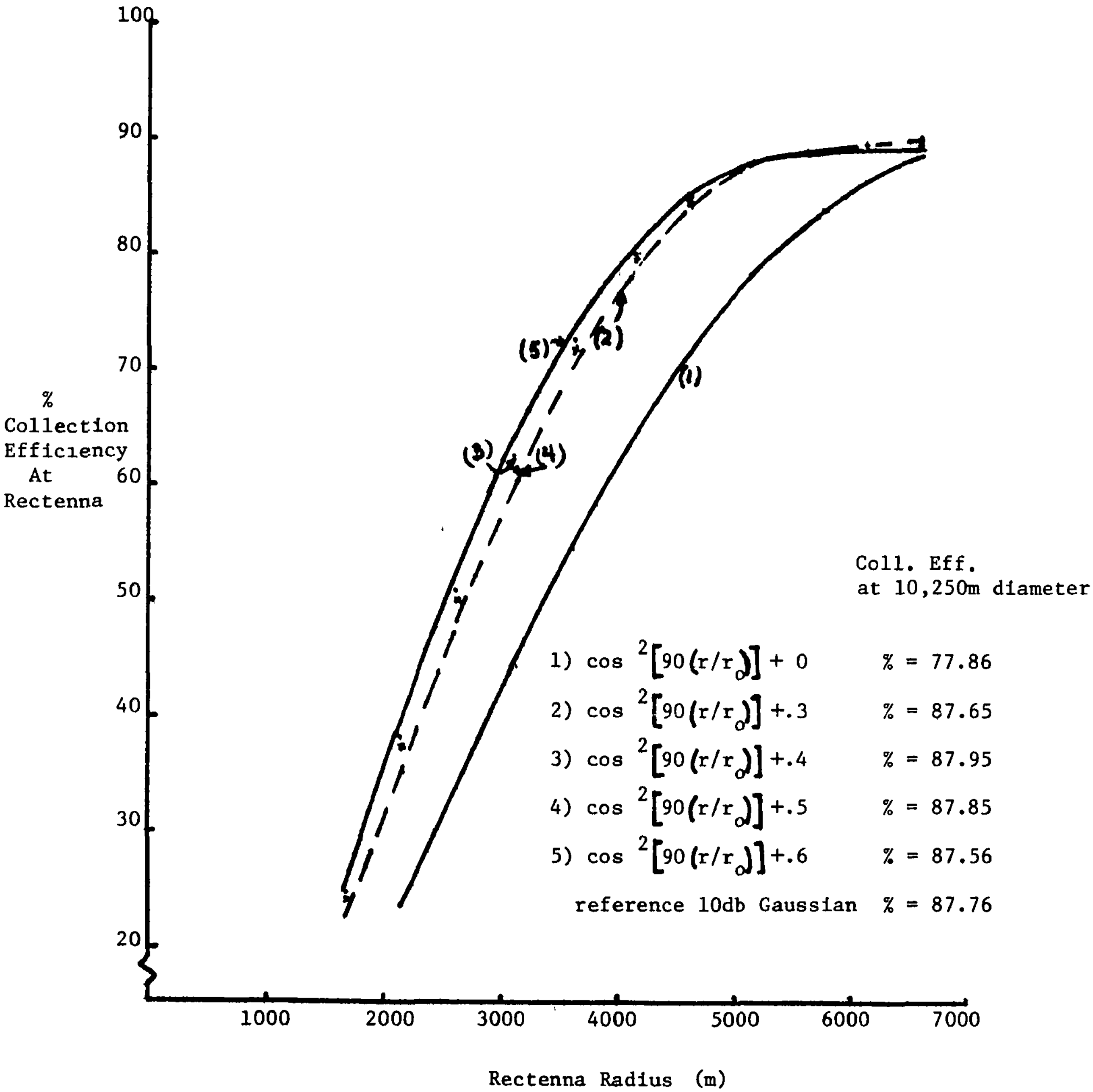


Figure IV.C.2 - Collection Efficiency vs Various Cosine Tapers With Specified Parameters ($\sigma = 10^{o}$, $\pm$ 1dB, 2%)



The mainlobe and sidelobes of the antenna patterns at the rectenna are shown in figure IV.C.3 for the cosine function with a pedestal height of .4. The results indicate an improvement (a reduction) of 1.2 mw/cm^2 at boresight for the cosine function when compared to the 10db Gaussian taper function. There is also a considerable improvement in the sidelobe levels (a factor of 8 reduction) for the cosine function. Thus for the cosine distribution, the optimum parameters are

$$E_{(r)} = \cos^2\left[90^\circ\left(r/r_o\right)\right] + .4 \qquad (3)$$

It is interesting to note that the power density at the edge of the transmit array is approximately one-tenth (1/10) of the maximum density at the center of the array - which is also true for the 10db Gaussian taper function chosen as the reference. The maximum power density at the center of the transmit array is calculated to be 27.61Kw/m^2, which is higher than the present maximum limit of 21Kw/m^2 as determined by thermal limitations

(3) Quadratic - The quadratic on a pedestal illumination function is given by:

$$E_{(r)} = \left[1-\left(r/r_o\right)^2\right]^n + P \qquad (4)$$

The collection efficiency curves as a function of exponent weighting and pedestal height are shown in figure IV.C.4. The highest operating efficiency at the reference radius of 5125 meters is obtained with n = 2. Expanding the results to include varying the pedestal height as shown in figure IV.C.5, a maximum efficiency of 88.23% occurs for

$$E_{(r)} = \left[1-\left(r/r_o\right)^2\right]^2 + .4 \qquad (5)$$

The corresponding maximum power density at rectenna boresight is shown in figure IV.C.3 for this quadratic illumination function with a pedestal height of .4. An improvement of 1.0 mw/cm^2 (a reduction) is possible for the quadratic function when compared to the 10db Gaussian taper used as the reference. The sidelobe levels for the quadratic illumination are lower than those for the gaussian taper by a factor of 6.3.

As was seen to be true for both the Gaussian and the cosine functions, the quadratic illumination has the best performance when the power density at the edge of the transmit array is approximately one-tenth (1/10) of the maximum density at the center of the array. The maximum power density at the transmit antenna is 25.15 kw/m^2, which is better

Figure IV.C.3 -Power Density at Rectenna for Gaussian, Cosine, and Quadratic Tapers

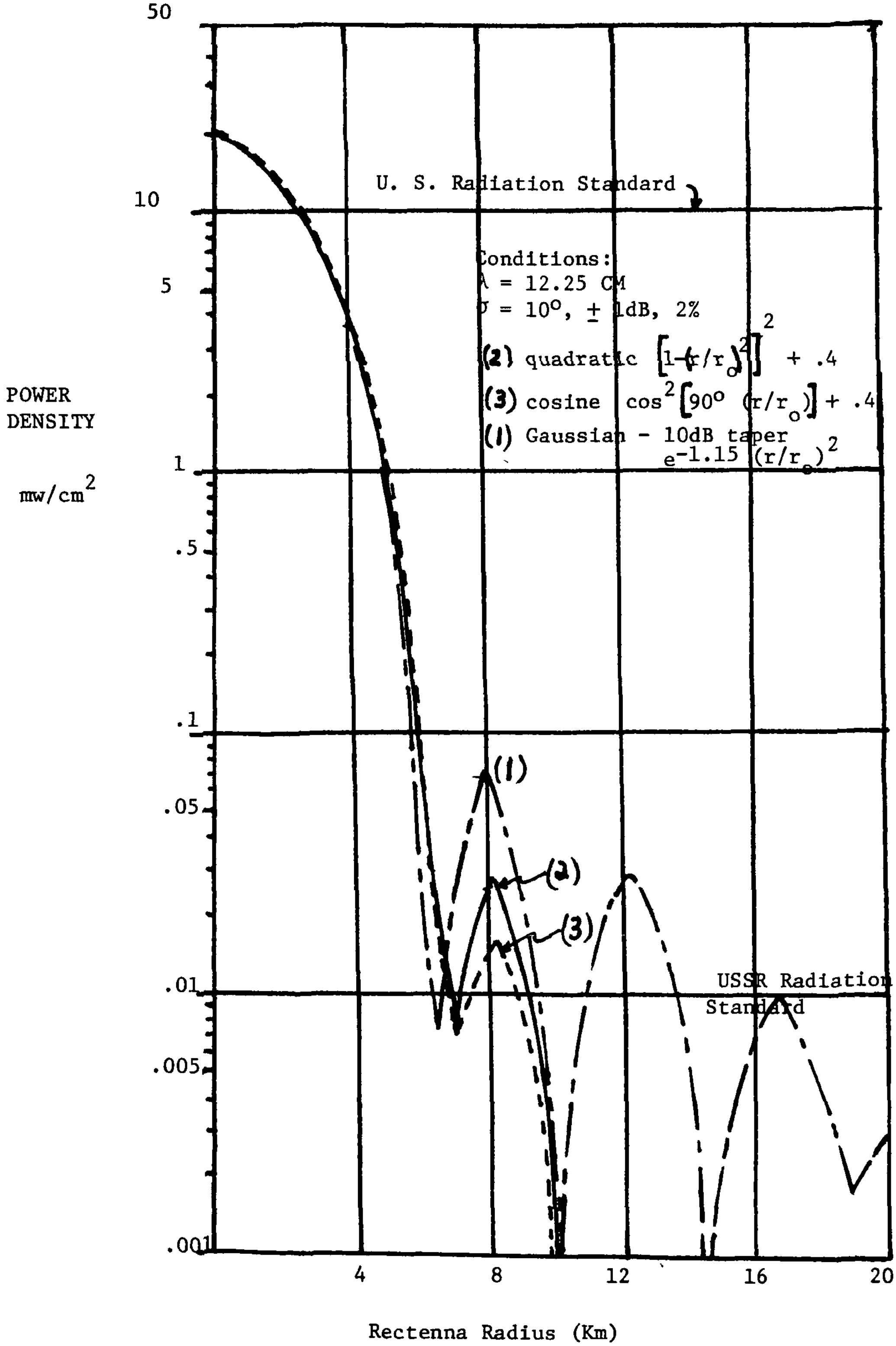


Figure IV.C.4 -% Collection Efficiency vs Various Quadratic Tapers With Parameters (σ = 10°, ± 1dB, 2%)

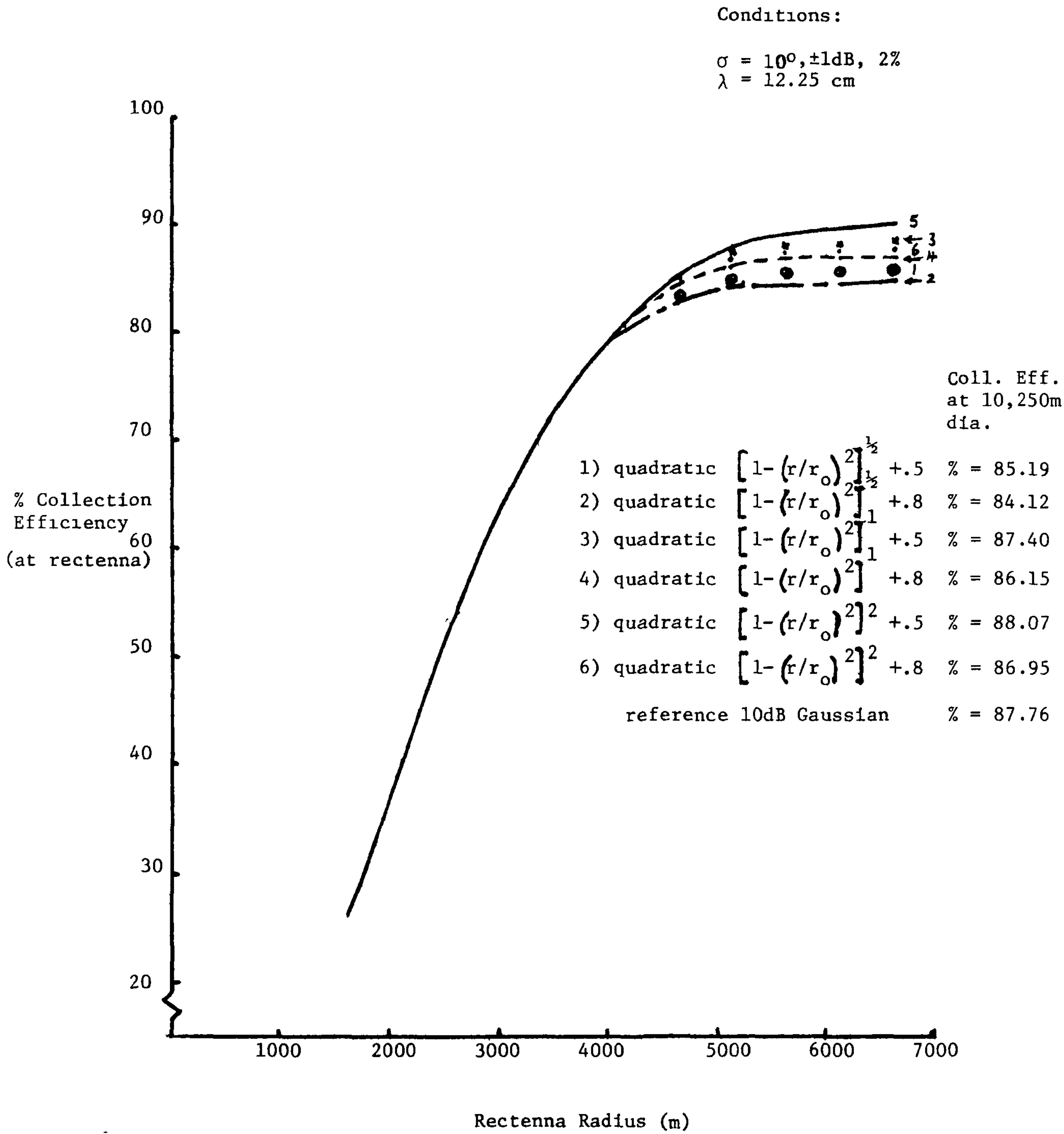
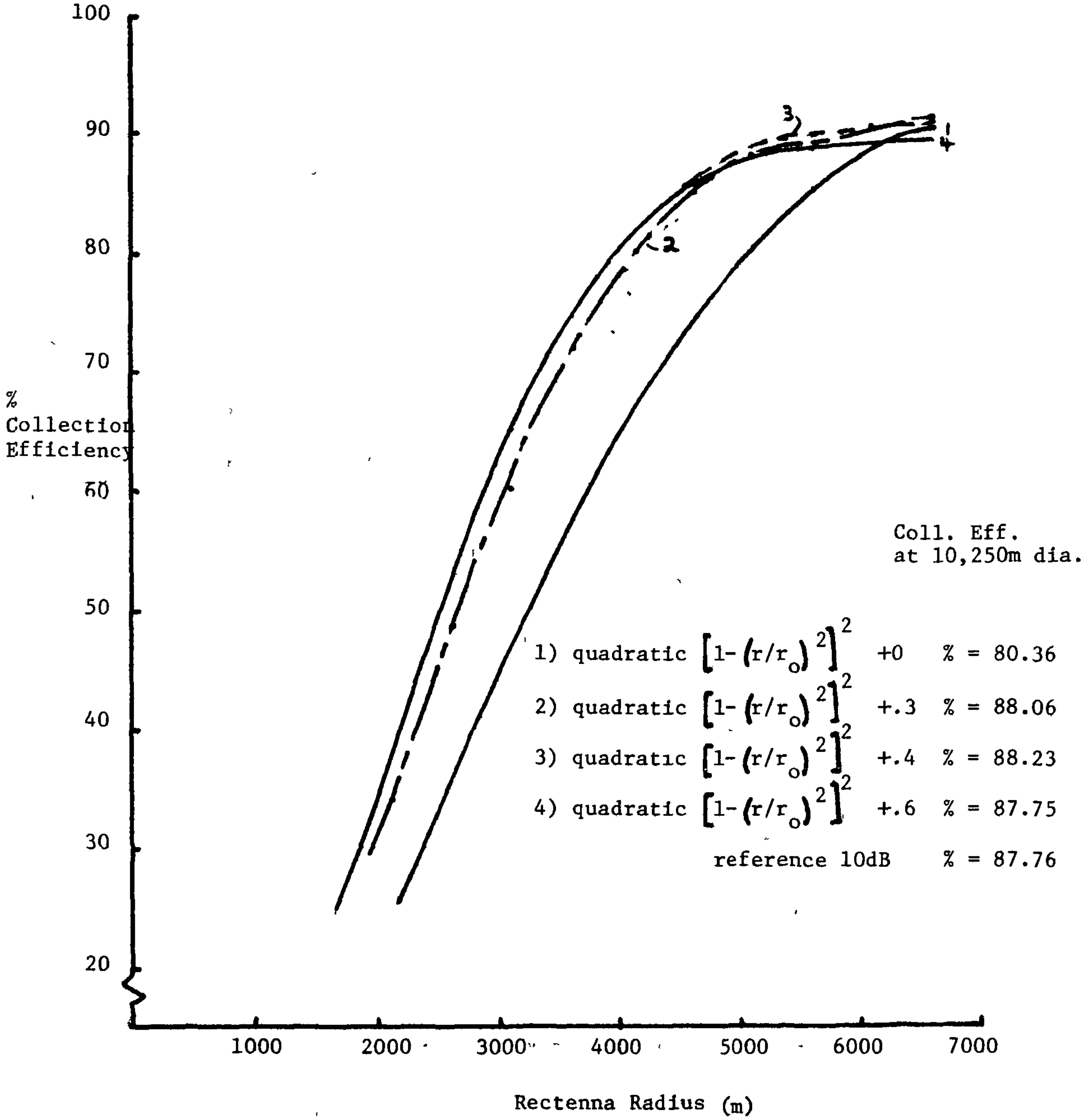


Figure IV.C.5 -Collection Efficiency vs Various Quadratic Tapers with Specified Parameters ($\sigma = 10^{\circ}$, $\pm$ 1dB, 2%)



(lower) by 2.5 kw/m^2 than that for the cosine function, but still exceeds the maximum set by thermal limitations.

Summary of Optimum Illumination Functions - The operating characteristics of each of the three illumination functions, i.e., Gaussian, cosine, and quadratic, optimized to achieve maximum collection efficiently within a rectenna radius of 5, 125 meters are summarized as follows:

Function	Amplitude Distribution E(r)	% Collection Efficiency for 10, 250m Rectenna $\sigma = 10^o$, $\pm$ 1db, 2%	Max. Power Density at Rectenna (boresight) (mw/cm^2)	First Sidelobe Level Referenced to Main Beam	Maximum Power Density at Transmit Array (Kw/m^2)
Gaussian (10dB taper)	$-1.15\left[r/r_o\right]^2$	87.76	22.0	-24.7db	20.88
Cosine	$\cos^2\left[90^o\left(r/r_o\right)\right] + .4$	87.95	20.8	-30.9db	27.61
Quadratic	$\left[1-\left(r/r_o\right)^2\right]^2 + .4$	88.23	21.0	-28.7db	25.15

When considering the two constraints for maximum power density in the transmit array and at the rectenna, the 10db Gaussian taper has the best overall performance of the three optimized illumination functions. If the power tubes become more efficient and thereby reduce the thermal limitations in the transmit array, the quadratic illumination should be considered. At this time, however, the Gaussian taper is the most viable candidate.

IV.C.1.b System Size Tradeoffs - The initial sizing for the Satellite Power Station was a 1 Kw transmit array with 5 GW of DC power out of the rectenna. This sizing was based upon: (1) achieving the maximum output power (2) a thermal limitation of 21 KW/m^2 in the transmit array and (3) a peak power density limit of 23 mW/cm^2 in the ionosphere. There are however some advantages in having a smaller system size. Commercial utility companies can probably handle 1 GW increments easier than 5 GW; the implementation cost of a 1 GW system is lower; and the sidelobe radiation levels near the rectenna are lower. Disadvantages of smaller systems include lower end-to-end microwave transmission efficiency and an increase in the overall cost of electricity (mills/KWH).

The downlink operating frequency is another tradeoff consideration. The SPS reference system operates at 2.45 GHz, which is at the center of a 100 MHz band reserved for government and non-government industrial, medical, and scientific (IMS) use. This band has the advantage that all communication services operating within the 2450 $\pm$ 50 MHz limits must accept any interference from other users. There is another IMS band at 5.8 GHz which should be considered. One way to reduce the terrestial land usage requirements for the SPS rectenna is to increase the operating frequency while maintaining the same antenna size. This reduction in rectenna size must, however, be traded-off against the large temporary degradation in transmission efficiency under extremely adverse weather conditions at the higher frequency.

The purpose of this section is to determine the end-to-end microwave transmission efficiency for smaller SPS systems operating at different frequencies. The variable parameters include:

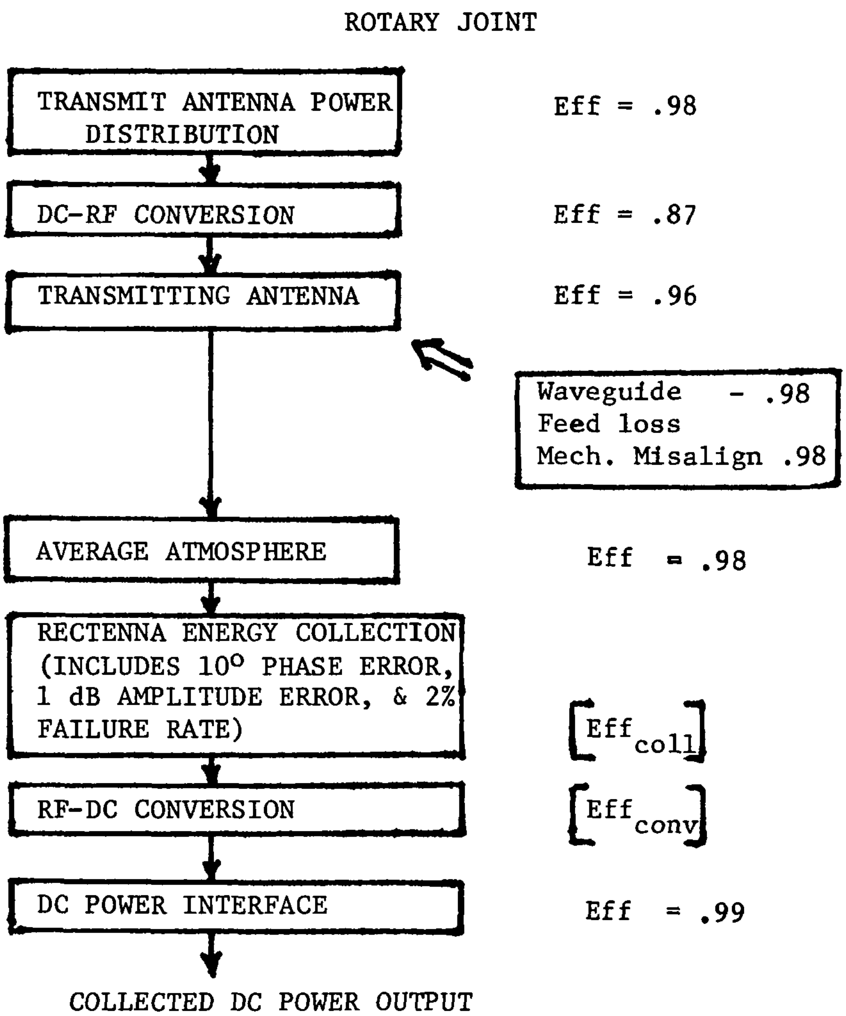
- Ground DC power output (1 - 5 GW)
- Transmit antenna diameter (.5 - 2 Km)
- Rectenna diameter (3.8 - 12 Km)
- Rectenna RD-DC conversion efficiency (77 - 90%)
- Transmit frequency (2450 MHz, 5800 MHz)

The nominal microwave transmission efficiency, from the rotary joint in the satellite to the DC/AC power interface at the output of the rectenna, is shown in figure IV.C.6. This end-to-end efficiency, for f = 2450 MHz, may be written

$$\text{Microwave Eff} = .794 \left[\text{Eff}_{\text{coll}} \;\text{X}\; \text{Eff}_{\text{conv}} \right] \qquad (6)$$

For the reference system given in the initial JSC report where $\text{Eff}_{\text{coll}} = .88$ and $\text{Eff}_{\text{conv}} = .90$, the microwave link efficiency is 62.88% (reference IV.C.1.). This efficiency will be used as a reference for comparing smaller SPS systems.

Figure IV.C.6 -Nominal Efficiencies for the Microwave System (2450 MHz)



The RF-DC conversion efficiency, Eff_{conv}, depends upon the input power level to the rectifying diodes connected to the half-wave dipole elements in the rectenna. During the past year excellent progress has been made at the Lewis Research Center, Jet Propulsion Laboratory (JPL), and Raytheon Company in developing higher efficiency diodes, particularly at lower power levels. This RF-DC conversion efficiency, consisting of the collection efficiency of the individual dipole elements times the diode rectifying efficiency, is shown in figure IV.C.-7 as a function of incident power density. This data assumes a 3 percentage point improvement in the next decade over the present achievable conversion efficiency. This rectenna configuration has multiple dipole elements feeding a single rectifying diode at low density levels. The operating frequency for this efficiency curve is 2450 MHz.

In equation (6) the rectenna collection efficiency, Eff_{coll} is a function of incident power density and incremental rectenna area while the conversion efficiency, Eff_{conv}, varies only with power density. The end-to-end microwave transmission efficiency may be rewritten

$$\text{Microwave Eff} = .794 \left[\sum_{x=o}^{x=R_R} \frac{P_{D(x)} \Pi \left(r_x^2 - r_{x-1}^2 \right)}{P_{TRANS}} \quad Eff_{conv}(P_{D_x}) \right] \quad (7)$$

where P_{TRANS} - the total power transmitted through the atmosphere

R_R - the outer radius of rectenna

x - the incremental rectenna radius

$P_{D(x)}$ - the incident power density at a distance X from rectenna boresight.

For a sample calculation of microwave efficiency, the power density patterns for the main lobes of a 1 Km transmit array operating at f = 2450 MHz and f = 5800 MHz are shown in figure IV.C.-8. The total DC power out of the rectenna is varied from 5GW down to 1 GW. Integrating under these curves and then dividing by the total transmit power through the atmosphere, the rectenna collection efficiency is obtained. Collection efficiencies for various transmit array sizes operating at 2450 MHz as shown in figure IV.C. 9. Each of these antennas have a 10db, guassian taper for the illumination function, with error parameters of $\sigma = 10^{o}$, $\pm$ 1db, 2% failures. The microwave efficiency for each SPS system size may now be determined from the data in these last three figures and applied in equation (7).

The degradations in end-to-end microwave efficiency for smaller SPS sizes are summarized in figures IV.C. 10 and IV.C. 11 for operating frequencies of 2450 MHz and 5800 MHz, respectively. The 62.88% reference efficiency is that performance expected for 1Km, 5GW SPS

Figure IV.C.7 -Total Rectenna Efficiency (Collection Eff X Conversion Eff) vs Incident Power Density

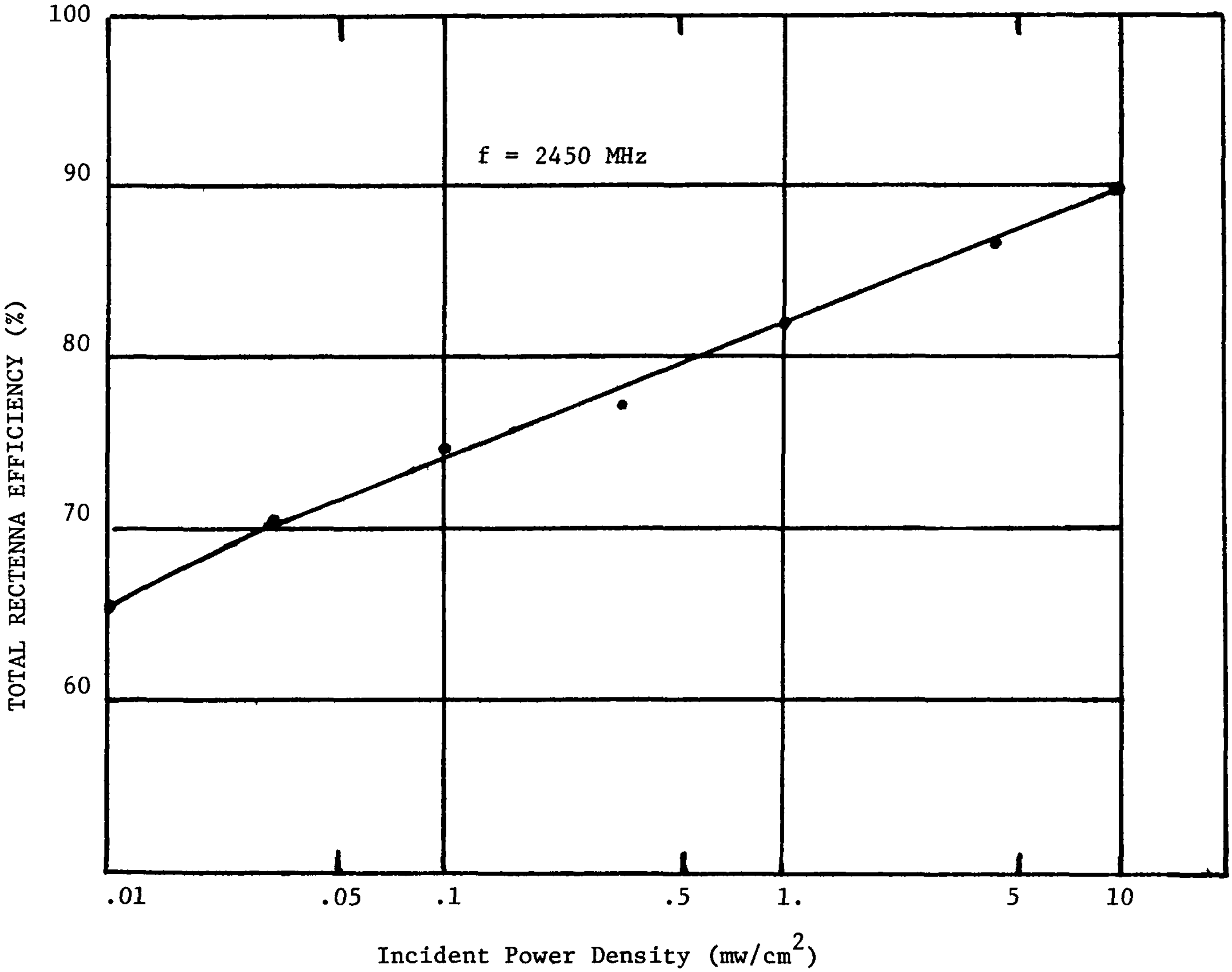


Figure IV.C.8 -Power Density at Rectenna for 1Km Array
f = 2450 MHz

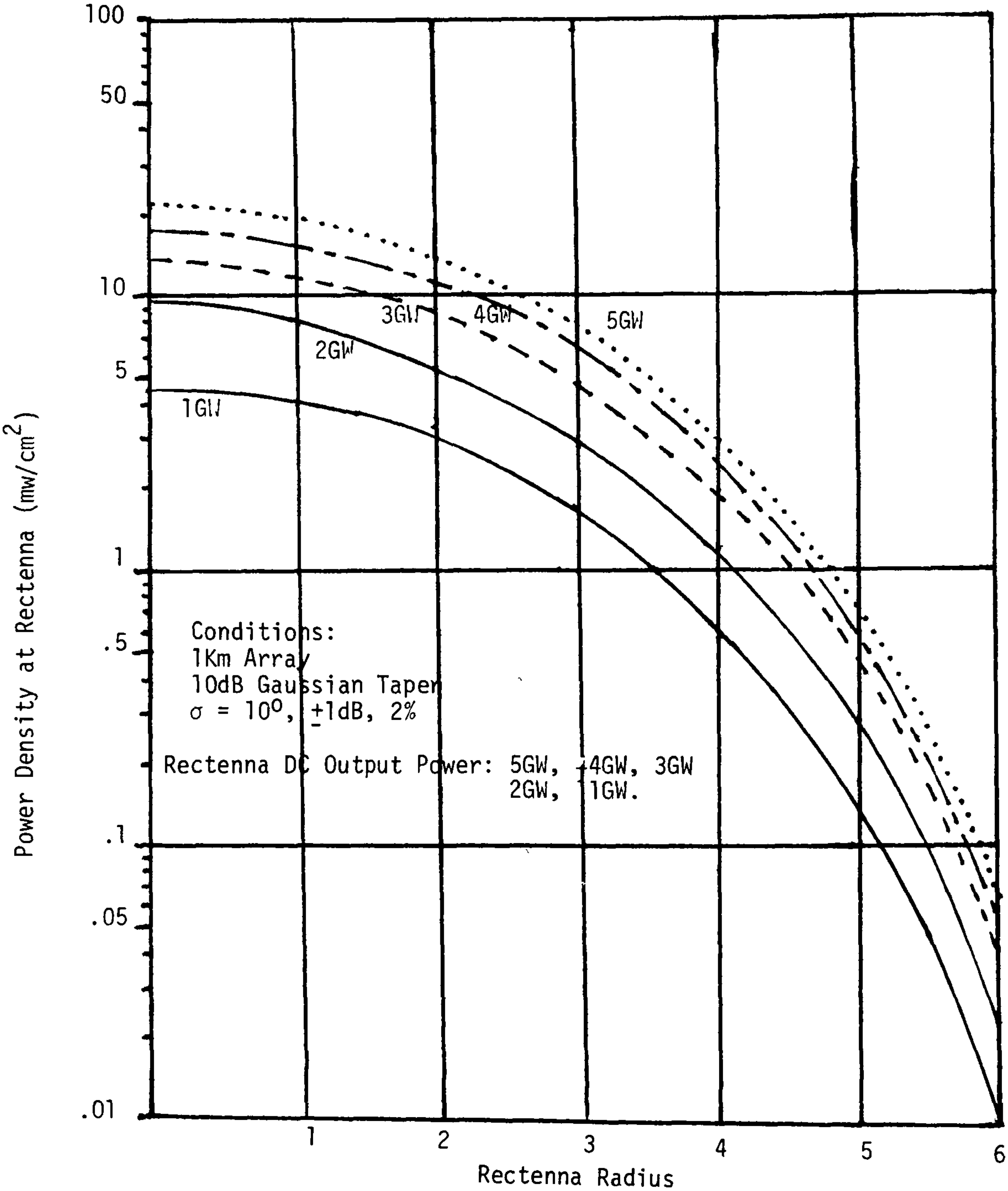


Figure IV.C.9 -% Rectenna Collection Efficiency vs Specified Parameters for Various Array Diameters

($\sigma = 10^{0}$, $\pm$ 1dB, 2%; 10dB Gaussian taper)

f = 2450 MHz

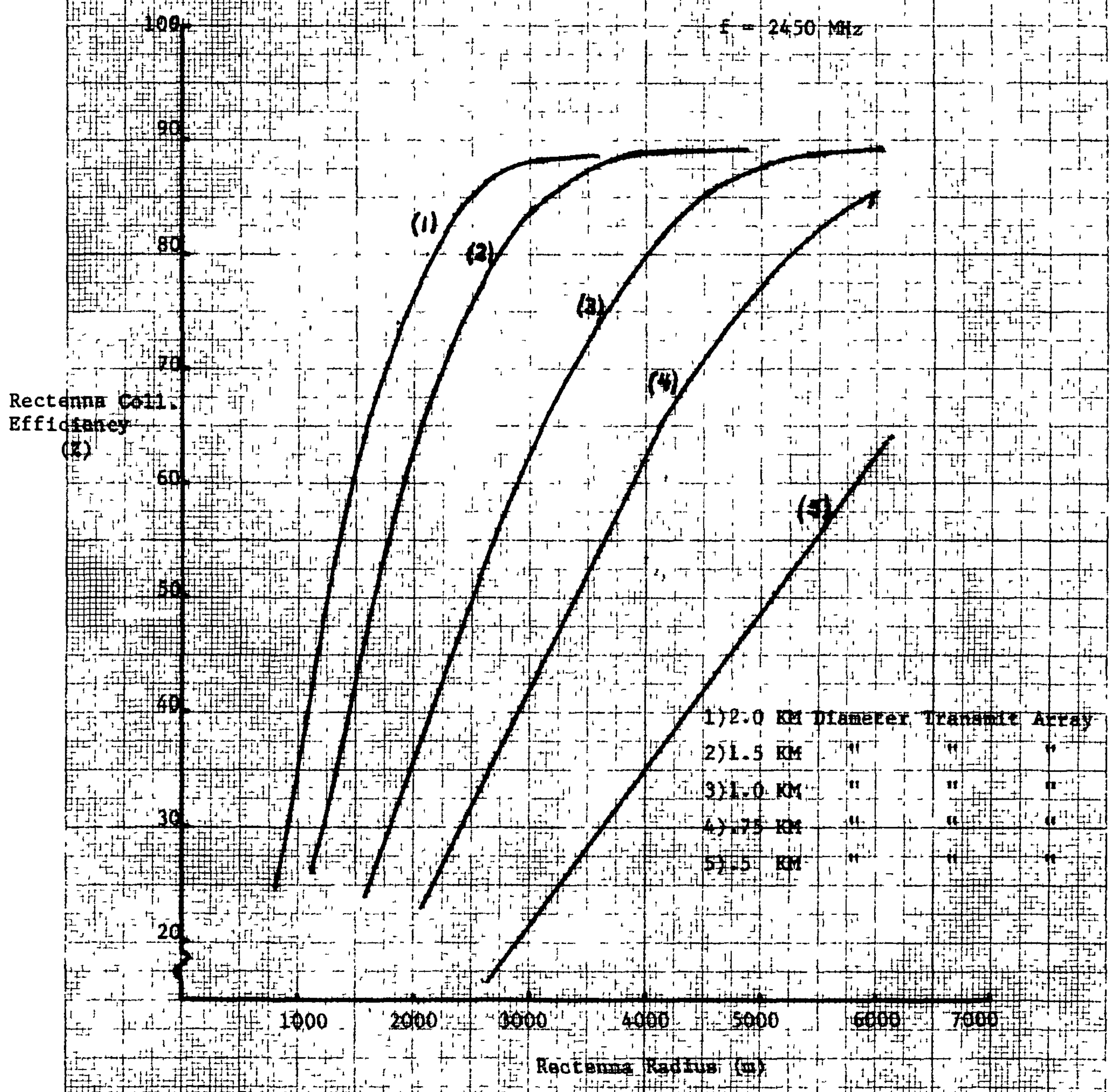


Figure IV.C.10.

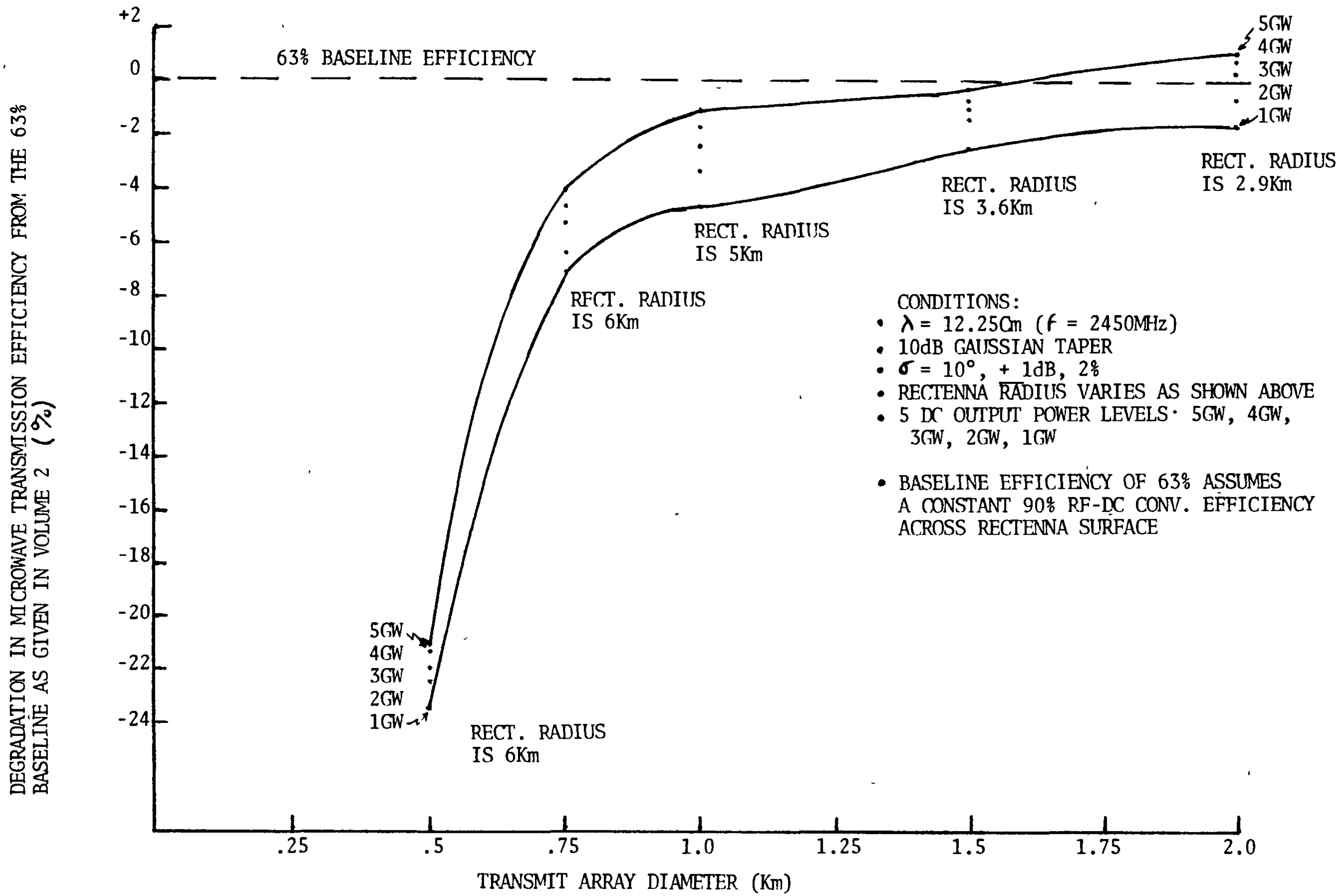
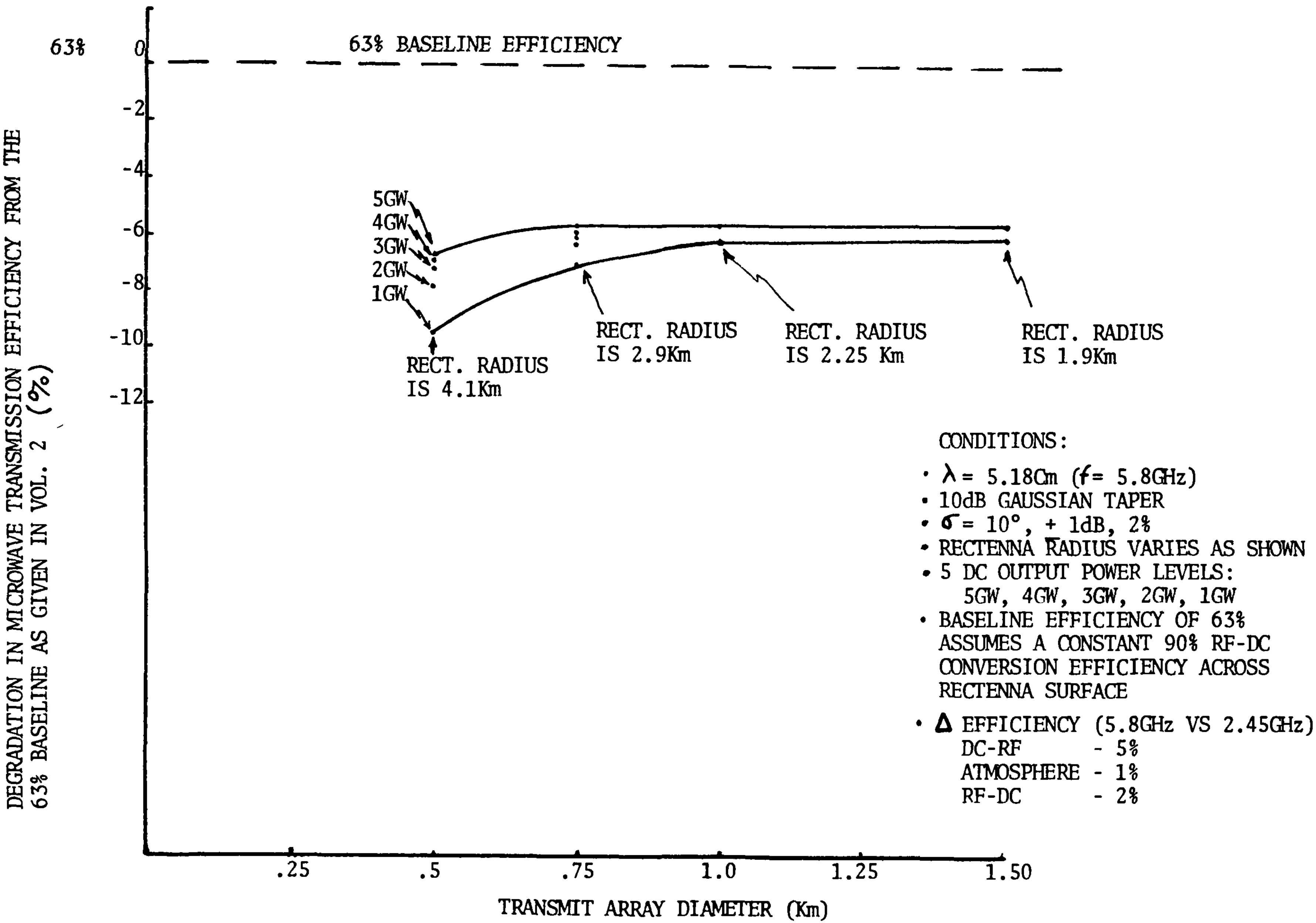


Figure IV.C.11



C-2

system operating with a constant 90% RD-DC conversion efficiency in the rectenna.

The difference in performance between the 5 GW and the 1 GW systems as shown in figure IV.C.10 is due to a reduction in rectenna conversion efficiency at the reduced power density levels associated with the 1 GW system. Also, for transmit arrays with a diameter less than 1 Km, the power beam is dispersed over a wider area at the ground due to reductions in antenna gain. This dispersion reduces the amount of energy intercepted by the rectenna and further reduces the RF-DC conversion efficiency. The data indicates that smaller SPS powers are feasible, provided the antenna size is not reduced. That is, a 1 Km, 1 GW SPS system will have only a 4-5% (percentage points) reduction in microwave transmission efficiency as compared to a 5 GW system.

The transmission efficiency for systems operating at 5800 MHz as given in figure IV.C.11 is interesting in that there is very little degradation in performance at the reduced power levels. The reason is that the power density levels at the rectenna are considerably higher for the 5800 MHz systems and hence, little degradation in RF-DC conversion efficiency occurs as the power is reduced. There is also a constant degradation relative to the 62.88% reference efficiency due to lower efficiencies in several of the microwave subsystems operating at the higher 5800 MHz frequency. These degradations include a 5% reduction in DC-RF conversion efficiency in the microwave tubes (82%); a 1% reduction in the nominal atmospheric transmission (97%), and a 2% reduction in RF-DC conversion efficiency from the curve shown in figure IV.C.7. These transmission efficiencies for the 5800 MHz systems do not take into account the large degradations in atmospheric transmission during heavy rain storms. Since there could be as much as a 50% reduction in total transmitted power at 5800 MHz through a heavy rain, rectennas for these systems could have intermittent power reductions unless located in dry, southwest regions.

There is significant reduction in rectenna size at the higher frequency as shown in figure IV.C.12. If rectenna costs and land usage requirements become major factors, then operating at 5800 MHz should be seriously considered.

The sidelobe patterns in the near-vicinity of the rectenna are shown in figure IV.C.13 for several SPS antenna configurations and operating frequencies. The nominal 5 GW, 1 Km antenna with the 10 db gaussian illumination taper and operating at 2450 MHz is used as a reference (Curve 2). The smaller, 1 GW, 1 Km system has the power density reduced by a factor of 5 as given in curve 3. By going to a larger antenna size and increasing the taper, the sidelobe levels can be further reduced. By increasing the operating frequency to 5800 MHz as shown in curve (4), the first sidelobe level is down to .14mw/cm^2, while the radius required to meet the USSR radiation level of .01 mw/cm^2 is reduced to 9 Km.

Figure IV.C.12

TYPICAL SPS SIZING ALTERNATIVES

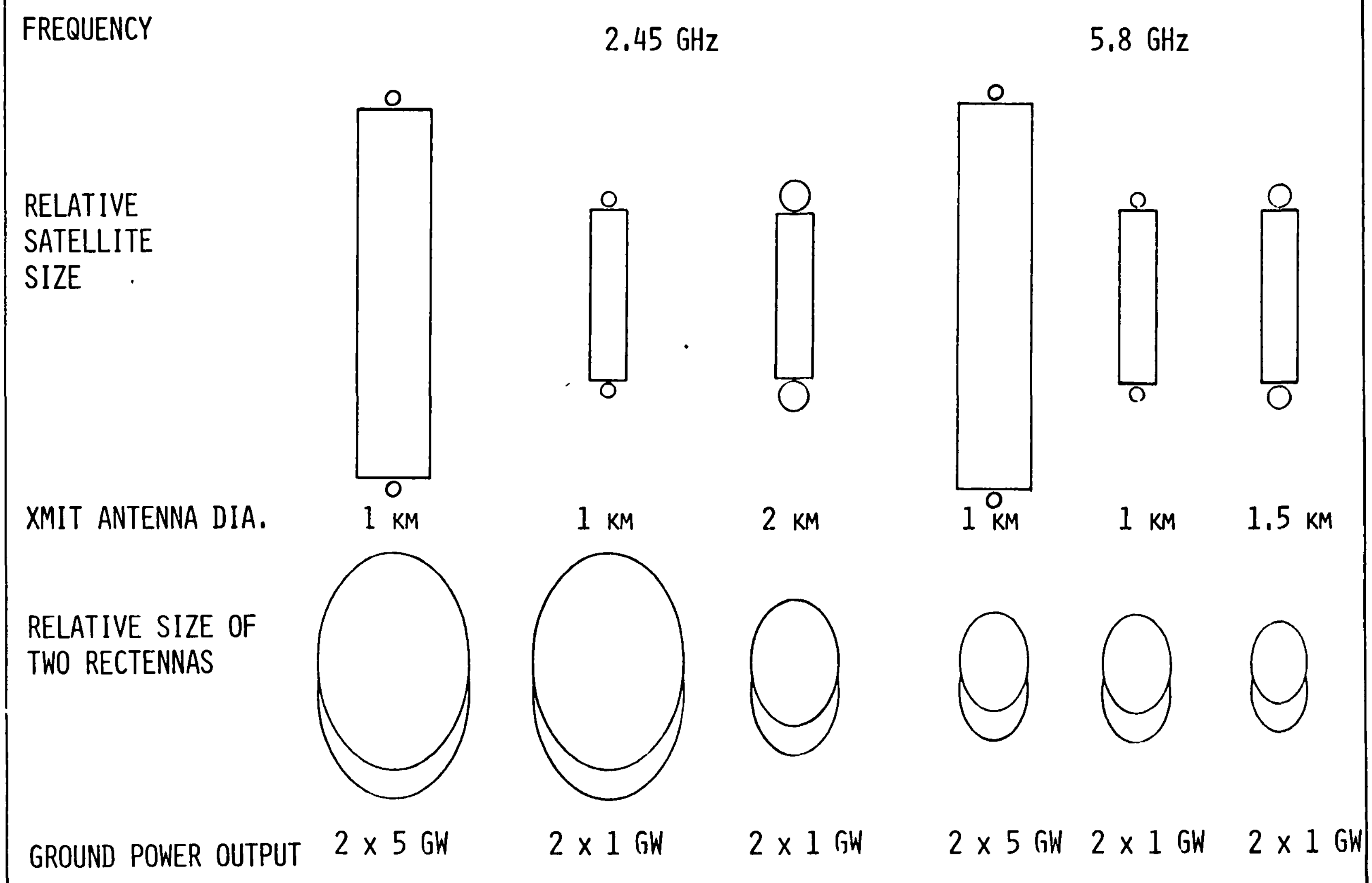
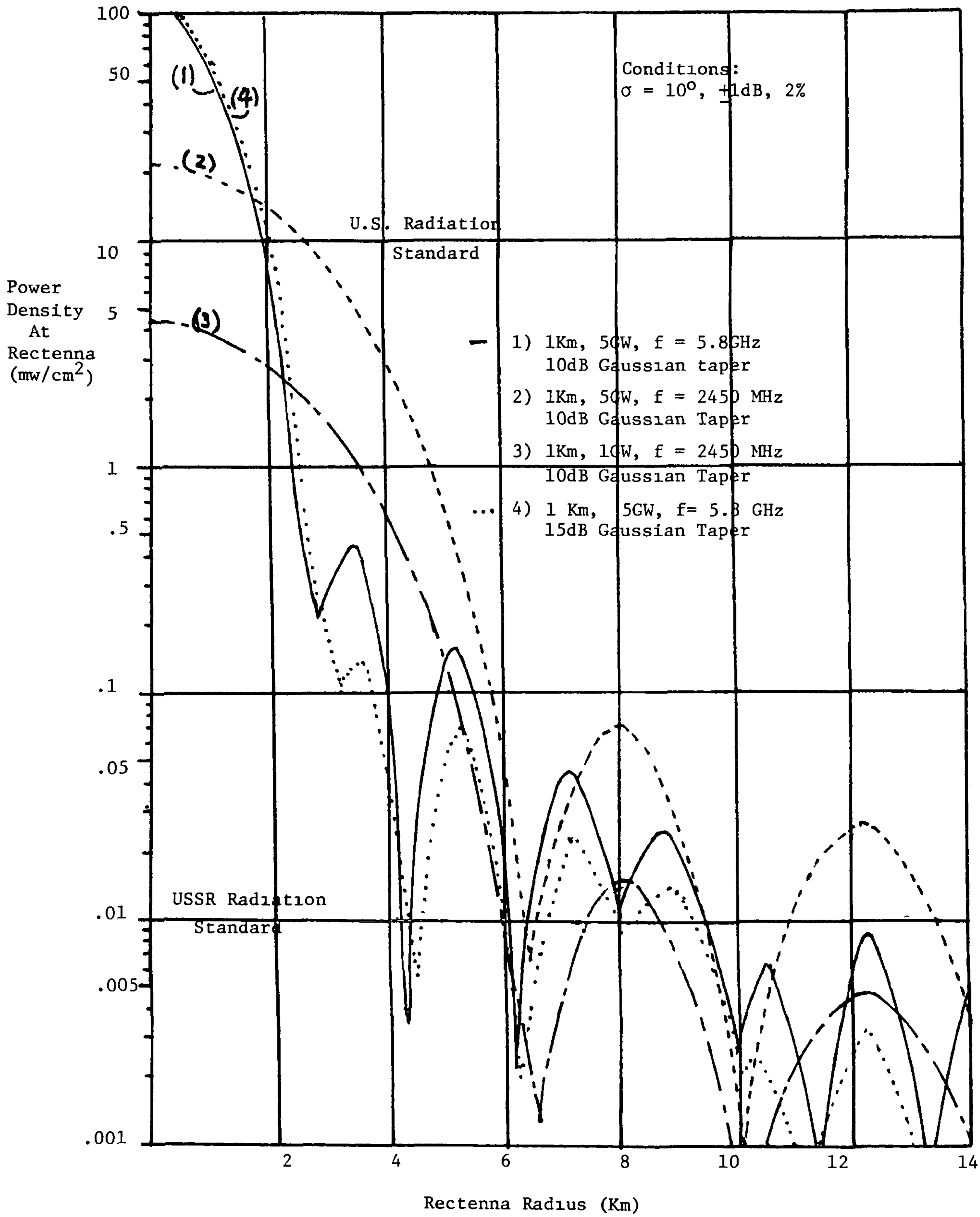


Figure IV.C.13 -Power Density at Rectenna For Various SPS Sizes and Frequencies



The results of the system sizing study indicate:

- Reduced power levels have only small degradation in efficiency ($\simeq$ 4% loss between 5 GW and 1 GW).

- Antennas with less than 1 Km diameter @ 2450 MHz and .75 Km diameter @ 5800 MHz are not practical.

- Larger transmit antennas will reduce rectenna area and sidelobe levels.

- 2450 MHz and 5800 MHz frequencies have similar end-to-end transmission efficiencies for lower transmit powers.

- Primary advantage of 5800 MHz frequency is reduced rectenna land area (1/5) but must be traded off against adverse weather degradations.

IV.C.1c. Cluster Concept Evaluation - The concept of dividing a single, large SPS satellite into a number of smaller, physically separate subsatellite was evaluated. Under MSFC contract NAS 8-31842, The Aerospace Corporation, recently investigated a number of SPS cluster configurations (reference 2). These schemes included segmented microwave transmitting antennas, combined with various solar array configurations.

The purpose of this analysis is to compare the rectenna collection efficiency of a single large microwave transmit antenna with that expected from a multiple of smaller antennas. In concept, these multiple antennas are physically separate, but phased together to transmit to one rectenna. One particular cluster configuration of interest is shown in figure IV.C.14. There are three 576-meter diameter antennas whose summed area is equivalent to that of a single 1 Km diameter antenna. The multiple antennas are separated a variable distance d. Each of the three antennas have a 10db, gaussian taper, with error parameters $\sigma = 10^{o}$, $\pm$ 1db, and 2% failures. The components of the field patterns from all three transmit antennas are vectorially summed at each point in the ground rectenna to get a composite pattern. The peaks and nulls for the sidelobes of the composite pattern are dependent upon the separation of the antennas.

The percent collection efficiency as a function of rectenna radius is shown in figure IV.C.15 for the three-antenna cluster. At a radius of 5,125 meters the cluster collection efficiency is only 60% as compared to the 88% efficiency for the single antenna. Thus the cluster antenna concept has a poor microwave transmission efficiency in comparison to a single large antenna. This degradation in performance is due to high sidelobes and grating lobes for the segmented antenna. The amount of degradation depends upon the size and spacing of the multiple antennas. In summary the cluster concept is not recommended due to degradations in rectenna collection efficiency.

Figure IV.C.14 -"Cluster" Antenna Concept

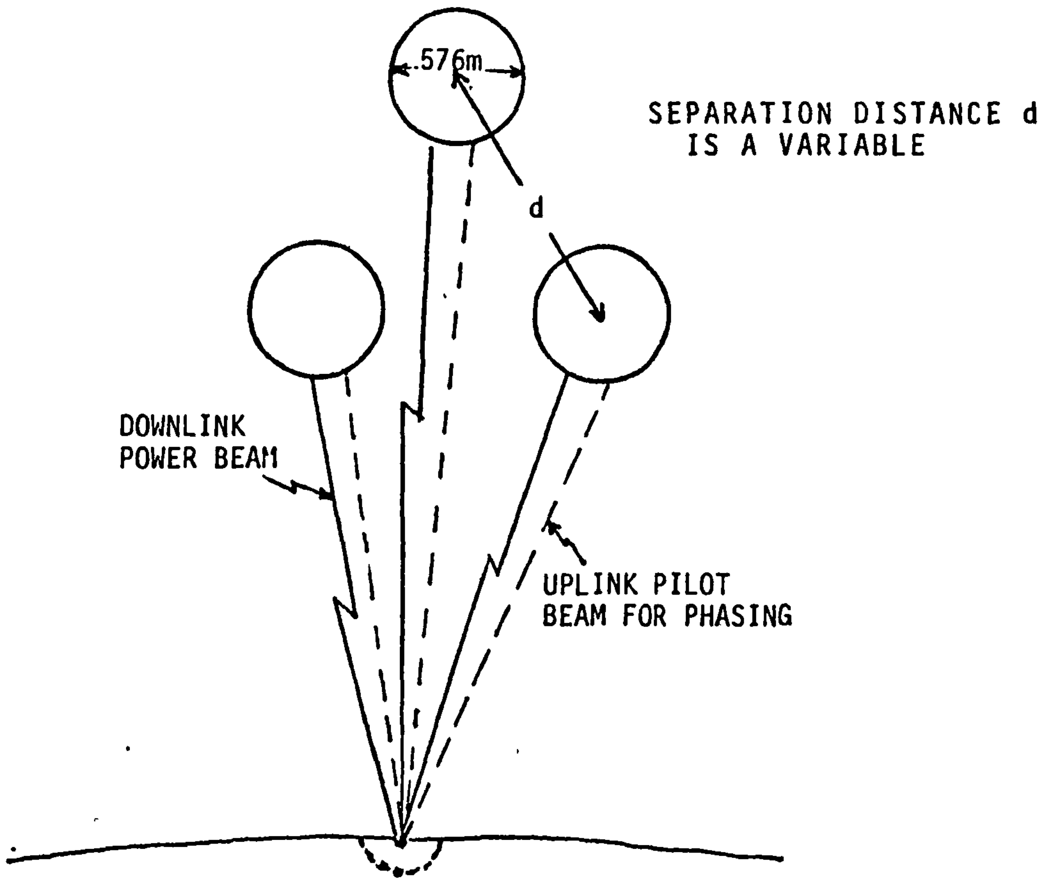
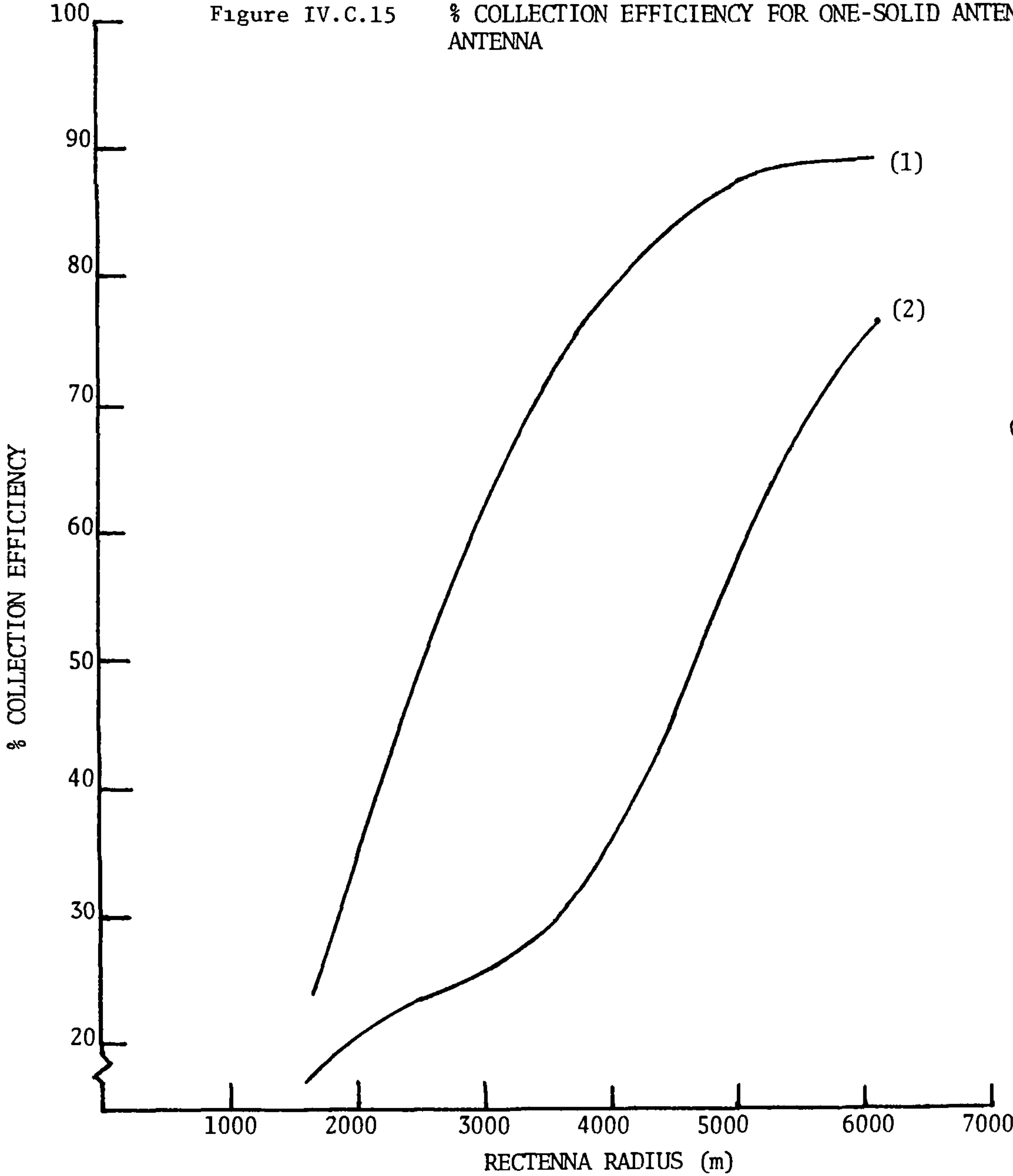


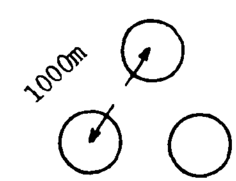
Figure IV.C.15 % COLLECTION EFFICIENCY FOR ONE-SOLID ANTENNA AND A THREE-SEGMENTED ANTENNA



CURVES:

(1) - 1Km DIAMETER ANTENNA;
$\sigma = 10°$, + 1dB, 2% FAILURE RATE
10dB GAUSSIAN TAPER; $\lambda = 12.25$cm

(2) - 3 - 576m DIAMETER ANTENNAS;
$\sigma = 10°$, + 1dB, 2% FAILURE RATE
10dB GAUSSIAN TAPER;
SPACING = 1000m.



IV.C.1.d. <u>Antenna Pointing Parameters</u> - In the August 1976 JSC report the mechanical pointing tolerance for the microwave antenna was given as $\pm$ 3 arc minutes, which resulted in a 2% loss in effective subarray gain. The corresponding subarray size was approximately 10 meters by 10 meters for this 2% loss. Each subarray can be thought of as a single antenna which must be mechanically pointed towards the rectenna to within 3 arc minutes of boresight. The fine pointing is then performed by electronic phasing of the subarray beam with all the individual subarray beams.

The mechanical pointing requirement has two components: (1) the steering or pointing of the entire 1 Km microwave antenna towards the rectenna, and (2) the pointing of each subarray. The steering of the 1 Km array is a function of the attitude control system of the antenna. The subarray pointing is performed by initially aligning each subarray using three screwjacks attached to the structure.

This study investigates the former pointing requirement, i.e., steering of the entire 1 Km array, assuming the individual subarrays are perfectly aligned across a flat plane. This analysis considers only the amplitude effects of boresight misalignment. A follow-on study will calculate the magnitude of grating lobes produced by misalignments and will also determine the pointing requirements for individual subarrays.

The subarray antenna pattern is given by the equation:

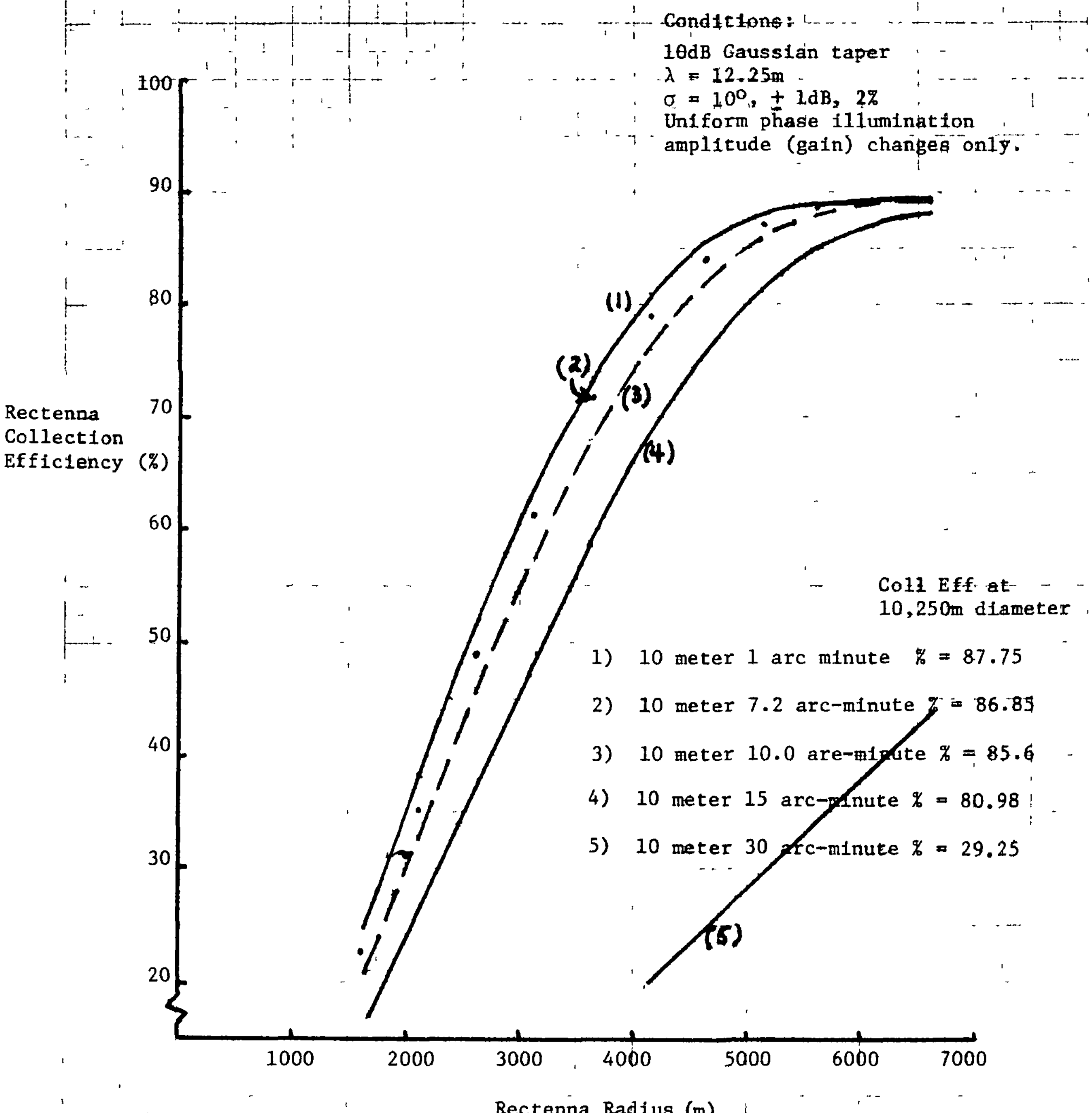
$$E_{(\phi)} = \frac{\sin\left[\frac{\pi L}{\lambda} \sin \phi\right]}{\frac{\pi L}{\lambda} \sin \phi} \qquad (8)$$

where ϕ - is the angle of boresight
L - is the length of the subarray

The reduction in subarray gains as a function of angle misalignment (ϕ) may be included in the transmit array/rectenna simulation program to compute collection efficiency. The results as shown in figure IV.C.16 and IV.C.17 indicate that antenna misalignments up to 7-arc minutes produce only a 1% degradation in collection efficiency. However a maximum misalignment of 15-arc minutes should not be exceeded - the SPS system would probably be shut-down if attitude control errors exceed 15-arc minutes.

The physical tilt at the edge of the total 1 Km array for a 7-arc minute boresight misalignment is $L = (500)\frac{7}{(60)}\frac{1}{(57.3)} = 1.02$ meters.

Figure IV.C.16 -% Rectenna Collection Efficiency as a Function of Total Array Misalignment



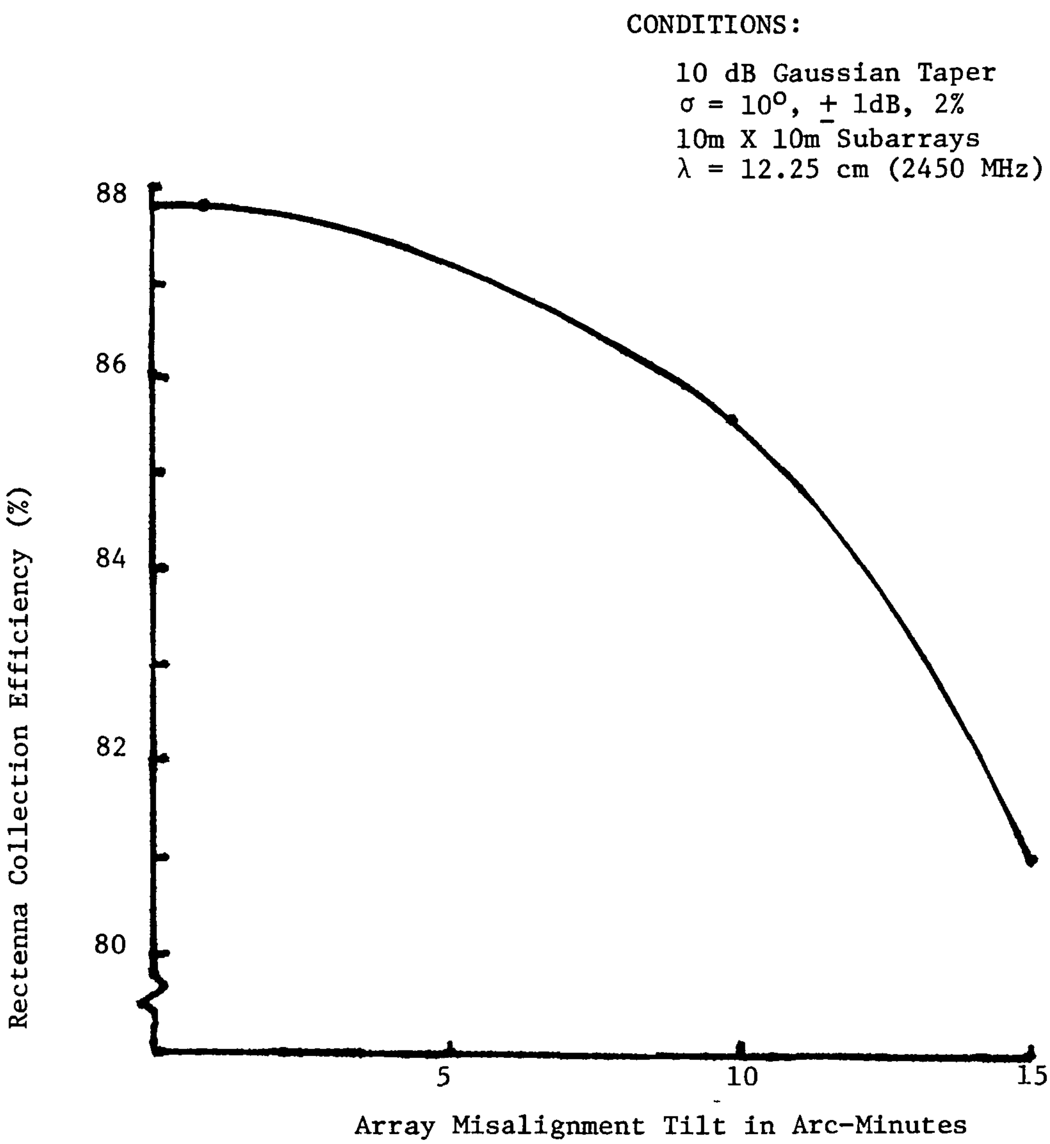


Figure IV.C.17 -Percent Collection Efficiency for Rectenna Diameter of 10,250 Meters vs Array Misalignment

R. H. Dietz
Tracking and Communications
Development Division

IV. SATELLITE POWER STATION

C. Microwave Power Transmission System

2. Microwave System Design Concepts

As a result of the JSC in-house study effort last year, documented in JSC 11568, "Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts, " dated August 31, 1976, it is recognized that the microwave system will require development in three major areas. These are the microwave generators (DC/RF converters), the phase control system, and the transmitting antenna array and subarrays. These three areas have continued to be investigated to the extent that in-house capabilities and contract funding would allow.

In addition to coordinating with Lewis Research Center on the work they have contracted on the amplitron, JSC awarded a contract to Varian Associates, Inc., to determine and evaluate the optimum electrical characteristics of an existing 50 kilowatt Klystron operating at 2.45 GHz.

Work also began on the design and analysis of the phase control system to be used on the microwave power transmission system. The Lincom Corp., was awarded a contract to evaluate phase control techniques, and develop a baseline system.

In-house efforts continued on developing the transmitting antenna array and subarray conceptual designs. These three areas will be discussed in the following sections.

IV. SATELLITE POWER STATION

C. MICROWAVE POWER TRANSMISSION SYSTEM (MPTS)

2. Microwave System Design Concepts

Louis Leopold
Tracking & Communications
Development Division

a. Microwave Generators - Initial feasibility studies for converting solar power in geosynchronous orbit into microwave power at 2.45 GHz for transmission to earth indicate that only amplitrons and klystrons achieve efficiencies in excess of 80 percent which are the required goals of the SPS program.

Klystron

Preliminary evaluation of a klystron amplifier at Varian Associates indicates that its overall efficiency with a depressed collector augmented can be as high as 85 percent if the power output is kept at 50 kW or higher. To do this, klystrons must use a beam-focusing field with the body-wound solenoid providing one possible solution. Actual emission tests predict a potential life of 20 to 40 years. However, many tests of a high-efficiency flight qualified klystron are required to determine the validity of reliable operation for 30 years.

The advantages and disadvantages of a klystron continuous wave amplifier for the SPS are as follows:

Advantages

1. High gain amplifier
   a. Low RF drive
   b. Phase control at low RF level
2. High power output
3. Potential high efficiency (optimum in narrow bandwidth klystron)
4. Relatively low noise output (amplified shot noise)
5. Harmonics over 30 db down
6. Potential long life
7. Bakeable solenoid (tube bakeout with solenoid power)
8. Small efficiency change with temperature
9. Control and protective electrodes

Disadvantages

1. Requires solenoid and heater power
2. Requires phase control (multiple tube use)
3. May require tuner trimming control
4. High beam voltage
5. Requires depressed collector for highest efficiency
6. Efficiency somewhat lower than crossed field devices

The estimated operating characteristics of the cw klystron for the SPS are as follows:

Frequency, MHz	2450
Bandwidth (3 db), MHz	3
Beam Voltage, kV	34-40
Beam Current, A	1.8-2.4
Power Output, kW	48-77
Beam Efficiency, %	75-80
Overall Efficiency, %	84-86
Saturated Gain, db	40-50
AM Noise, db	-130
PM Noise, db	-115
Heater Power, W	40
Electromagnet Power, kW	-1
Cooling	Radiation

The advantages of a klystron are its high gain of 40-50 db, allowing phase control at drive levels of one watt; very low noise, higher power per tube and bake-out in space with its own solenoid. The operating voltage of 35-40 kV, the tube size, the hot cathode and the requirement of a depressed collector to exceed 75 percent efficiency are some of its disadvantages.

The estimated physical characteristics of a 20 kW klystron and a 50 kW klystron for use in space are as follows:

	20 kW Klystron	50 kW Klystron
Length	25 1/2"	34"
Width (diameter)	12"	12"
Voltage	34 1/2 kV	40 kV

	20 kW Klystron	50 kW Klystron
Width Tube Only	-	5"
Width (tube & magnet)	-	12"
Weight	58 lbs.	75 lbs.
Cooling	Radiator (.8 square meter)	Heat Pipes Radiation (1 meter diameter)

To establish the current state-of-the-art of cw high power klystrons, tests have been done to determine and evaluate the optimum electrical characteristics of a cw 50 kW power output klystron at 2.45 GHz. The tube known as the VKS-7773 cw amplifier is a high efficiency, 2450 MHz, wide-band klystron originally designed for industrial heating applications and for terrestrial use. The characteristics which are being optimized are the tuning (narrow banding), the gain, and the efficiency before it is fully evaluated. Measurements will be made of the following parameters during optimum efficiency performance:

(1) Electron Beam Voltage

(2) Magnetic Field

(3) Cavity Tuning

(4) Variations in Load Impedance

(5) RF Drive Level

(6) Current

(7) Temperature of cathode and anode during various cw power operations

(8) Noise spectrum as a function of input current and as a function of transient conditions at start-up and shut-down

(9) AM noise and PM noise in a narrow bandwidth (1-3 KHz) for frequency displacement from the carrier frequency

(10) Gain and bandwidth

Some further technologies will be evaluated in the development of a spaceborne microwave power converter. They are detailed as follows:

(1) Minimum weight and operating power

(2) Adaptability to radiation cooling augmented with heat pipes

(3) Ultimate use of a multi-staged depressed collector to increase total efficiency

(4) Bake-out processing of the tube in space with its own solenoid

(5) Mechanical design compatible with launch vibrations

(6) Open envelope

(7) Operating temperature in the space environment

(8) Low emission density cathode to comply with the design objective of a 30-year lifetime

(9) Provision for frequency stabilization

(10) Design for phase stability and minimize the change in phase characteristics with variations of parameters

(11) Design for GEO environment with radiative rejection of waste heat

Automated Klystron Manufacture - An order for 100 or so high power klystrons today is a "large" order. Manufacturing techniques are not greatly different from those employed in a job shop where a great deal of individual personal attention is focused on the tubes by various individuals. Functional organizational arrangements are often employed to reduce manufacturing costs, but tube designs are not changed greatly from those stemming from development.

An order of hundreds of thousands of tubes to be delivered at a high rate of 5000 per month, for example, assumes at the outset that emphasis has been placed on klystron design for such large-scale manufacture. Individual parts must be shaped for fabrication on automatic or near-automatic machinery, such as automatic screw type machines. Stampings and coined parts must be used where feasible. Simplicity of design must be stressed in every area.

Parts are fabricated through a variety of other techniques, each chosen for its large volume applicability. Extrusion, powdered metal fabrication, centrifugal casting, photo etching, electro deposition and similar methods may be mentioned.

In assembly, self-stacking arrangements are used and/or simple fixtures maintain alignments. Automatic conveyor type furnaces are used for assembly brazing. Automatic machines are employed where welding is necessary.

Automatic exhaust and bakeout systems are used. Perhaps these would be patterned after the rotary exhaust systems used today in some cases. If hot testing is necessary, automatic test systems will be devised.

This may result in a completely new and different type of klystron factory, all facilities aiming at fabrication of the one device. The design of this unit represents a challenge as difficult, perhaps, as that of design of the klystron in the first place.

An estimated program for the development and test of a high efficiency SPS klystron is described as follows:

Phase 1: 18 months

Enhancement of present 75 percent basic klystron efficiency through computation, experiment, and modifications. Construction of several models demonstrating results.

Phase 2: 18 months

Computation and experiment leading to implementation of depressed collector. Introduction of work on lightweight focusing and on radiation cooling. Construction of several models demonstrating results.

Phase 3: 18 months

Continuation of work on collector depression, lightweight focusing, and radiation cooling. Continued study on possible further klystron basic efficiency improvement. Construction of several models demonstrating results. One or more of these to be tested in the space chamber. One to be flown in low earth orbit and tested in the space shuttle.

Amplitron

The estimated characteristics of an SPS amplitron are listed in table IV-C-1.

Comparison of the SPS amplitron with the existing microwave oven magnetron is noted in figure IV-C-18. Construction of the amplitron and the magnetron are similar and the manufacturing techniques would have much in common. The changes required to convert the magnetron to the amplitron and the cost per kilowatt with high volume production are listed.

A model of an amplitron interphasing with microwave waveguides and the waveguide transmitting through slots are shown in figure IV-C-19. The upper disk is the cathode radiator. The lower plate is the anode radiator for cooling purposes. The feed at the right of the amplitron accepts the input signal. The feed at the left of the amplitron conducts the amplified RF power output (6 1/4 kW) to the waveguide at the left.

The waveguide and antenna shown in figure IV-C-19 are not necessarily the SPS configuration. Other types of antenna arrays are under study in addition to the slotted array.

SPACE AMPLITRON

FREQUENCY	2.45 GHz
CW POWER OUTPUT	3-8 KILOWATTS
RF GAIN	5-8 dB
EFFICIENCY	83-88%
OPERATING VOLTAGE	15 - 20 KILOVOLTS
SIGNAL TO NOISE	>80 dB
VACUUM ENVELOPE	NONE
MAGNETIC FIELD	2600-3000 GAUSS
CATHODE AND ANODE COOLING	PASSIVE RADIATION FROM CIRCULAR COOLING FIN
WEIGHT	2.5-4.0 LB
CATHODE	PURE-METAL, SECONDARY EMITTING

TABLE IV-C-1

POWER CONVERSION FROM D.C. TO MICROWAVE DEVICE

UTILIZATION OF DESIGN RESOURCES

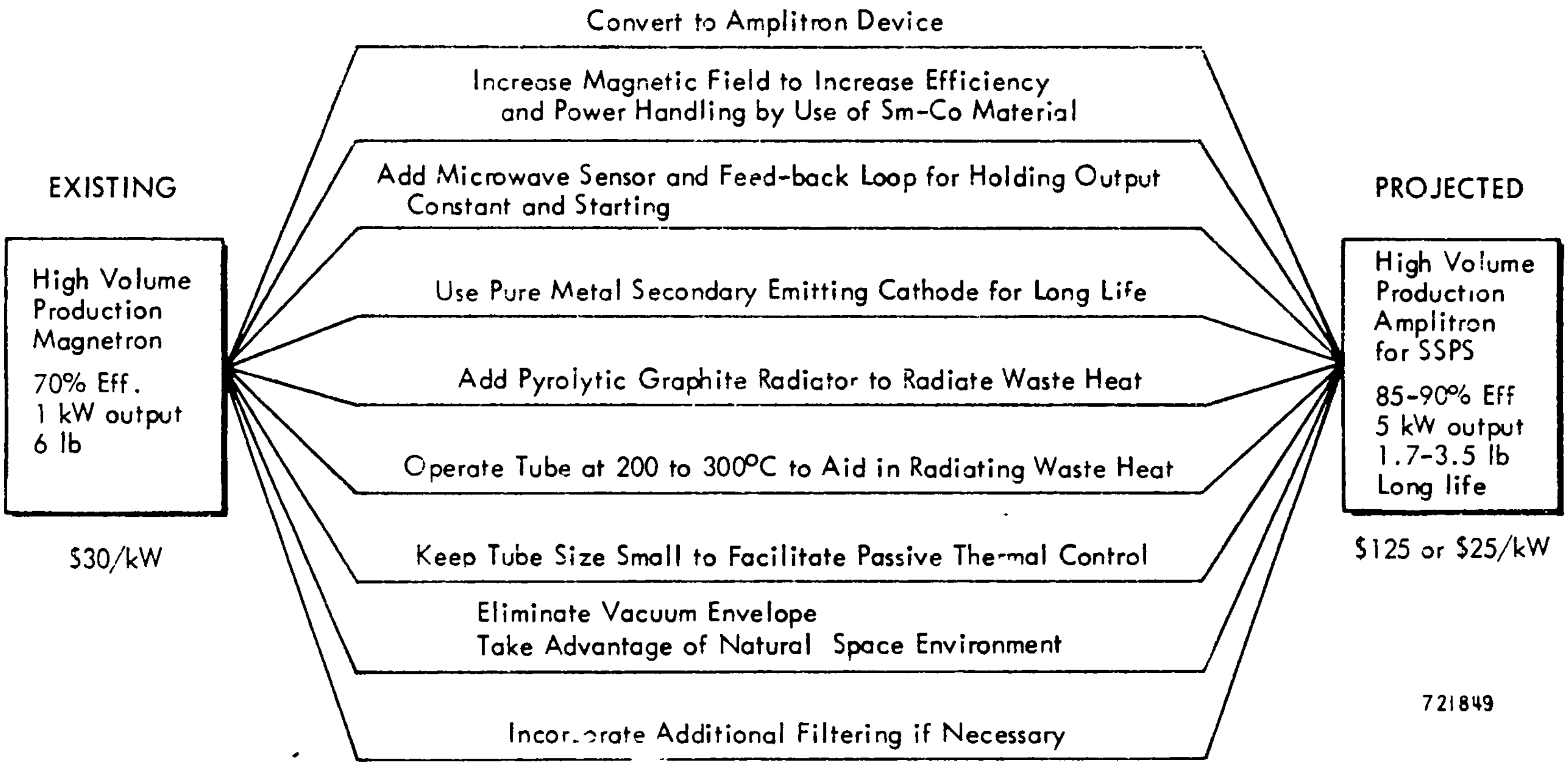


FIGURE IV-C-18

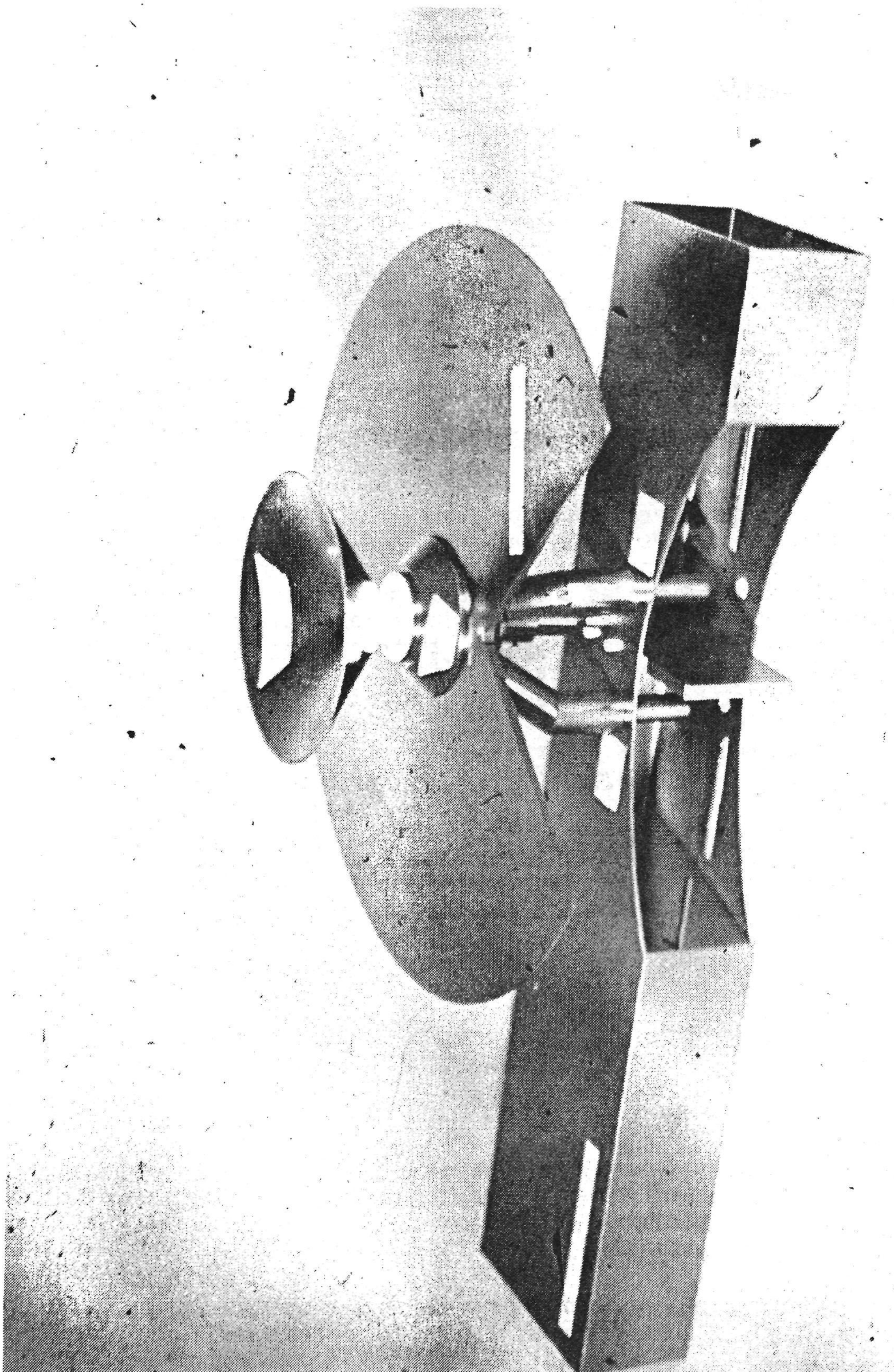


FIGURE IV-C-19

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b. Phase Control System - The Phase Control System is presently under study by Dr. W. C. Lindsey of the LinCom Corporation for Johnson Space Center. The study was initiated in April 1977, and Phase 1 will be completed in 6 months. In the time since the contract was awarded, some significant findings have been provided which are summarized in this section.

The SPS (solar power satellite) phase control problem basically breaks up into three areas: (1) the distribution of phase information to many distribution points in the system, (2) the phasing of the power amplifiers and (3) the antenna power beam steering.

In order to properly steer or point the antenna power beam, precise phase relationships of all the antenna subarray groups must be known, and must be maintained so that the resultant overall antenna power beam wavefront is pointed only toward the rectenna with minimal overflow beyond the rectenna surface. Using pilot beam phase conjugation, the pilot tone received signal at the center of the array system is used as a phase reference for comparison, at each subarray group, with the pilot beam phase received at that subarray group.

Three methods of distributing a constant reference phase to the many distribution channel/points in the array antenna system are under consideration: the master slave phase control method, the hierarchial master slave phase control method, and the total mutual synchronous method. Each of these approaches to distribution of the reference phase required for conjugation of the pilot signal at each subarray group is somewhat dependent on the geometrical layout of the system phase control components. Two geometric arrangements which provide the needed symmetry have been identified and are shown in figures IV-C-20 and IV-C-21, respectively.

These figures show sketches of a rectangular layout assuming 10 X 20 meter subarrays and a square layout assuming 14 X 14 meter subarrays. The dashed lines indicate interconnection of oscillators for phase distribution, and the dots indicate phase distribution (oscillator) points throughout the system. For both the square and rectangular configurations, a total of 4096 subarrays would be required with a total of 1365 oscillators or phase distribution points.

The concept behind the master slave system is described as follows: the master oscillator, located at the center of the antenna, phase locks to the pilot beam sent from the earth-based transmitter located at or near the receiveing rectenna. This phase is then

FIGURE IV-C-20 - SPS RECTANGULAR LAYOUT PHASE CONTROL

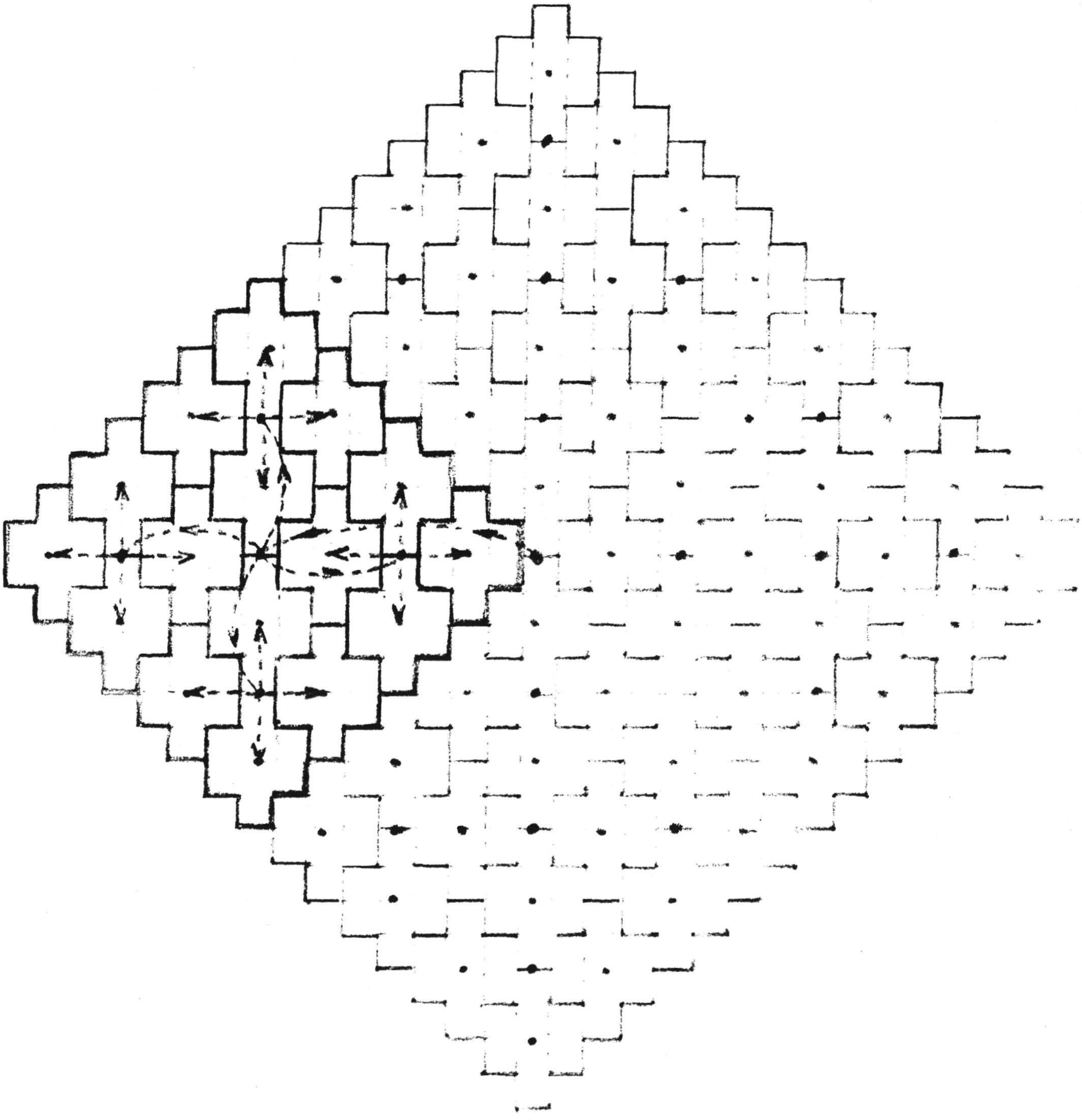
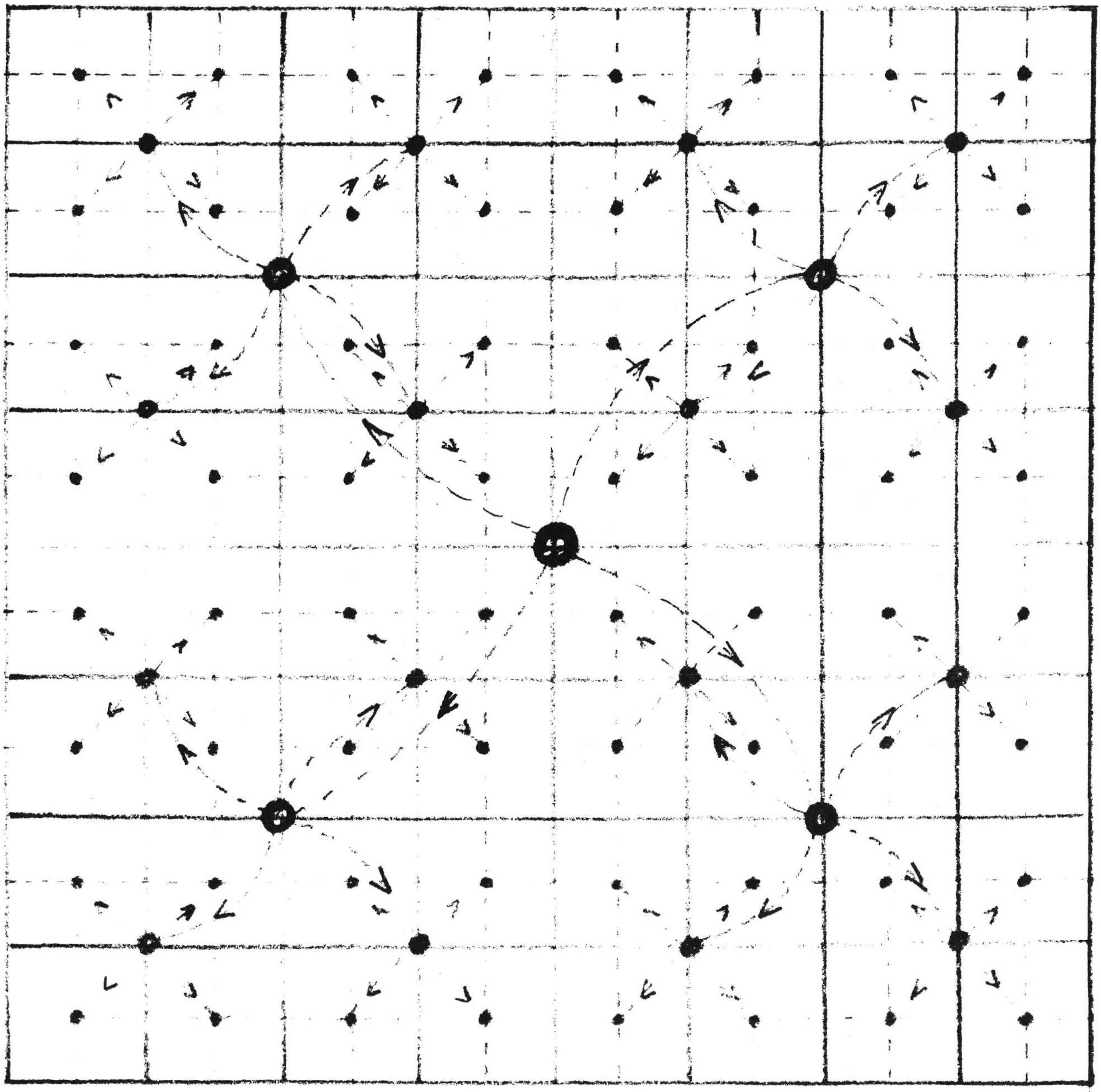


FIGURE IV-C-21 - SPS SQUARE LAYOUT PHASE CONTROL



distributed to the first level of slave oscillators by way of the master slave synchronization. There are four (2^{2X1}) such oscillators. All of them are symmetrically situated with respect to the master. These four oscillators in turn send the phase to the second level of slaves. This goes on until the fifth level of slaves is reached. There are 1024 (2^{2X5}) such oscillators. These oscillators are called terminal oscillators, for obvious reasons, and each of the terminal oscillators feeds four 10 X 20 meter subarrays in the rectangular configuration or four 14 X 14 meter subarrays in the square configuration.

The symmetry of the slaves around their immediate master is key to the control of line delays. If this symmetry could be strictly enforced, then, the phases at the terminal oscillators would all be the same.

The hierarchial master slave approach has a similar configuration to that of the foregoing system with the prime difference being that, at each level, the slave oscillators are phase-locked. Symmetry is still required to take care of the delays. This method is better suited for compensating delay variation due to non-uniform antenna temperature gradients, but it should be pointed out that none of these methods offers a complete solution to the temperature delays. This method also offers improved oscillator stability, i.e., less phase drifting due to the final level of mutual coupling.

The mutual synchronous system concept breaks up into two different classes depending upon processing of the signals. One of them is called the Equational Timing System and the other Returnable Timing System. Both of these compensate for the delay effects without invoking any kind of strict symmetry relation between the slaves, but do require symmetry between the master and the receiving oscillators. The main advantage of these two schemes is in providing compensation for tranmission line delay. Also, the uneven temperature gradients do not pose as great a problem. The major disadvantage that this system has is the large number of connections requiring a large number of cables, thus adding significant weight.

The area of power amplifier phase control is also under investigation and, again, can generally be considered in the master slave or mutual synchronous class of synchronization categories. The final stages will incorporate phase conjugation of the pilot signal at each subarray for pointing the power beam.

All of these phase distribution/control areas are still in the early investigative phases, and a preliminary recommended approach will not be arrived at until mid-July 1977.

Another area affecting the final power beam-forming system involves the effects of frequency separation between the pilot and

power beam signals. This area is presently under study, and recommendations are expected in mid-July, also. The basic effect of a frequency difference between the pilot and power beam is to squint or point the beam off at an angle incident to the arriving pilot beam. This effect may be compensated for by locating the pilot transmitter at the proper location relative to the earth-based rectenna. Also, use of different pilot frequencies may provide an effective method of phase control system isolation from one SPS to another. These effects have not yet been analyzed in detail and are part of the ongoing study.

IV. SATELLITE POWER STATION

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C. Microwave Power Transmission System (MPTS)

3. Structural Considerations

JSC in-house activity since the publication of the August 31, 1976, report has been concentrated on an MPTS structural concept more amenable to construction than that originally proposed. The new concept is a hexagonal planar truss composed of repeating tetrahedrons. (Thus, the concept is called the tetratruss.)

Contract effort was used to develop two "building block" deployable elements which may be used in a myriad of combinations for Shuttle sortie missions in support of SPS development. This contract (NAS9-14914) with The Boeing Aerospace Company culminated in an oral presentation at JSC on April 27, 1977. The Boeing Aerospace Company reported an application of the two "building block" elements to the JSC MPTS tetratruss concept.

The concept of two-tier or "double bed" construction was first used by the Grumman Aerospace Corporation in the development of a one-kilometer microwave antenna employing 18-meter-square subarrays in an earlier study. One tier serves as primary structure and a second tier offers subarray support on relatively close spacing. The secondary structure (second tier) is an adapter bridging the relatively coarse spaced primary structural joints to the subarrays. The tetratruss is a two-tier structure. A 10-meter-square subarray was modified to 10.746 meters by 9.306 meters (see Reference 1). This offers the same transmission surface area ($100m^2$) and matches an equilateral grid of the node points on the secondary planar truss (see figure IV-C-22). The secondary planar truss could be a deployable structure as reported in the NAS 9-14914 contract (Reference 2). Every other apex of the hexagonal secondary truss structure is supported by a primary node point (see Figure IV-C-23). The primary structure is composed of 660 members joined at 166 joints. Each of the 660 members is 130.284 meters in length. Sixty-one planar trusses compose the second tier structure. Each secondary planar truss and each subarray are supported at three points in a determinate manner. A determinate support allows a structure to be pointed without introducing internal stresses. Three options exist for mechanical pointing of the MPTS antenna. The options are: (1) a completely passive structure, (2) active control of 61 planar trusses, and (3) active control of 7854 subarrays. The determination of the viable option will be made pending control system analysis and engineering analysis of flatness and stiffness parameters.

An FY-77 contractual effort has been initiated to investigate the achievable flatness in the MPTS tetratruss antenna. Detailed review of manufacturing and fabrication variables will be made to determine if the initial flatness of the second tier structure of the tetratruss will meet the microwave

transmission requirements. A further objective is to determine if active figure control is required.

A NASTRAN model of the tetratruss (see Figure IV-C-24) was prepared in-house and sufficient runs were made for a parametric study of the tetratruss dynamic characteristics. A graphite material was assumed with Young's moduli of 137895×10^6 N/m^2 (20×10^6 psi) and 68948×10^6 N/m^2 (10^7 psi).

A density of 1661 kg/m^3 was used for all runs. Secondary structural mass and primary structural joint mass were assumed to be included in the 8,125,000 kg of nonstructural mass. The 8,125,000 kg mass was distributed in a manner that reflected the Guassian distribution of microwave power transmission.

Three cross-sectional areas, two values for Young's modulus, and two mass conditions were used in a parametric study of the NASTRAN model of the tetratruss. Figure IV-C-25 depicts the influence of mass on the structure for two values of Young's modulus. The cross-sectional area of each of the 660 members was held constant at .001 meters^2. The relatively large nonstructural mass lowers the first natural frequency less than one order of magnitude over the frequency for tare mass only. The frequency varies as the square root of the ratio of Young's moduli. Figure IV-C-26 illustrates the influence of the ratio of structural mass to total mass. The cross-sectional area of each of the 660 truss members was alternately set at .0001, .001, and .01 meters^2. Practical upper limits are apparent in seeking higher natural frequencies thru additional structural mass. The message is clear that the natural frequency of the MPTS structure may not be significantly altered from a relatively narrow one order of magnitude band. Figure IV-C-27 shows the well-ordered characteristic of the tetra-truss dynamic response. NASTRAN plots of the first 5 modes beyond the rigid body modes are shown in Figures IV-C-28 through IV-C-32. The deformed shape has been superimposed on the undeformed structure. The first two modes are anticlastic while the third mode exhibits polar symmetry. The NASTRAN structural response data herein presented offers a point of departure for the stability and attitude control engineer.

References

1. "Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts," Volume II-Detailed Report-JSC 11568, August 31, 1976

2. "Large Space Erectable Structure," Building Block Structures Study, Final Report - NAS 9-14914, April 1977, The Boeing Aerospace Company

NASA
S- 77- 22355

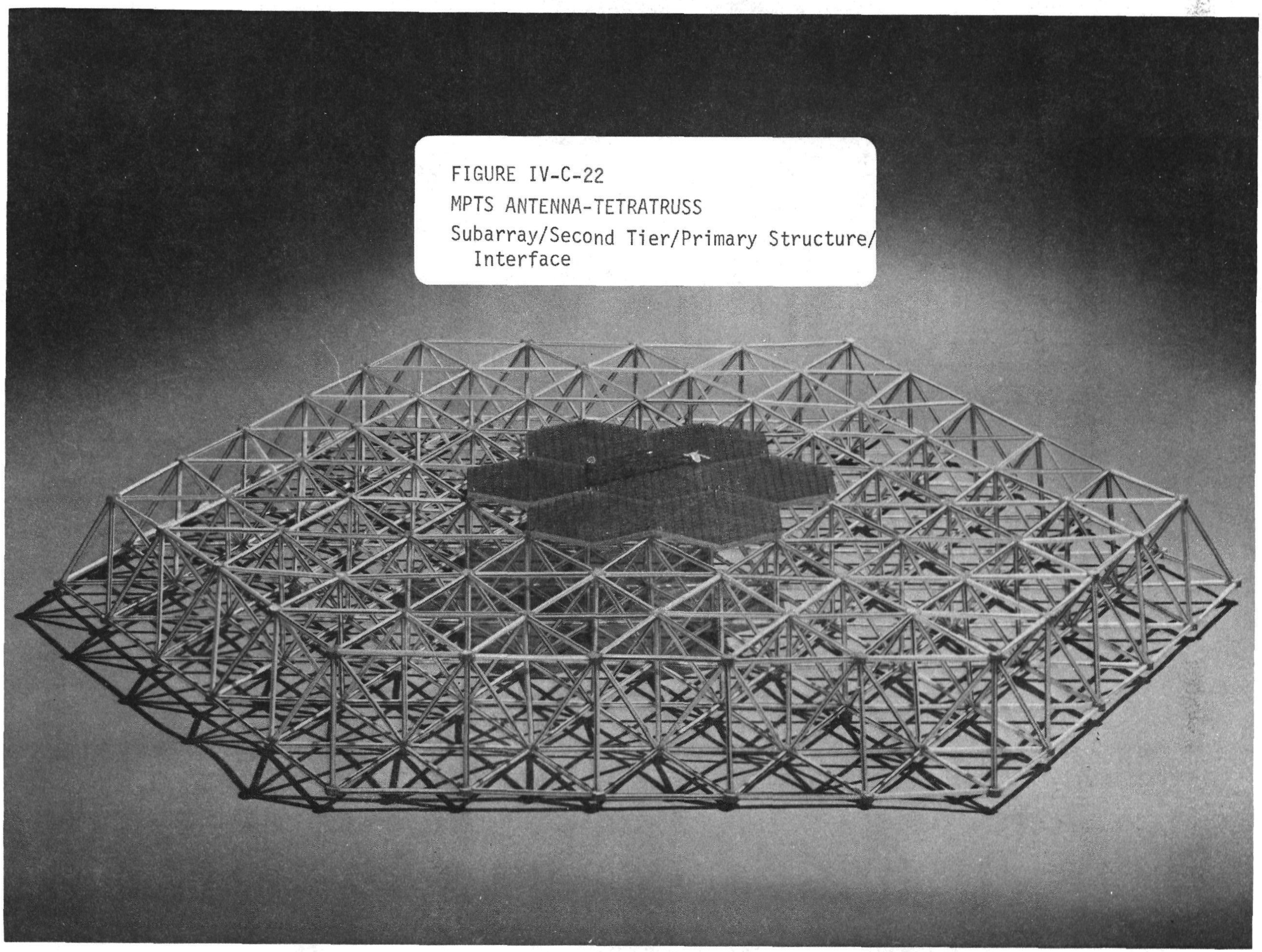

FIGURE IV-C-22
MPTS ANTENNA-TETRATRUSS
Subarray/Second Tier/Primary Structure/ Interface

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S- 77- 22856

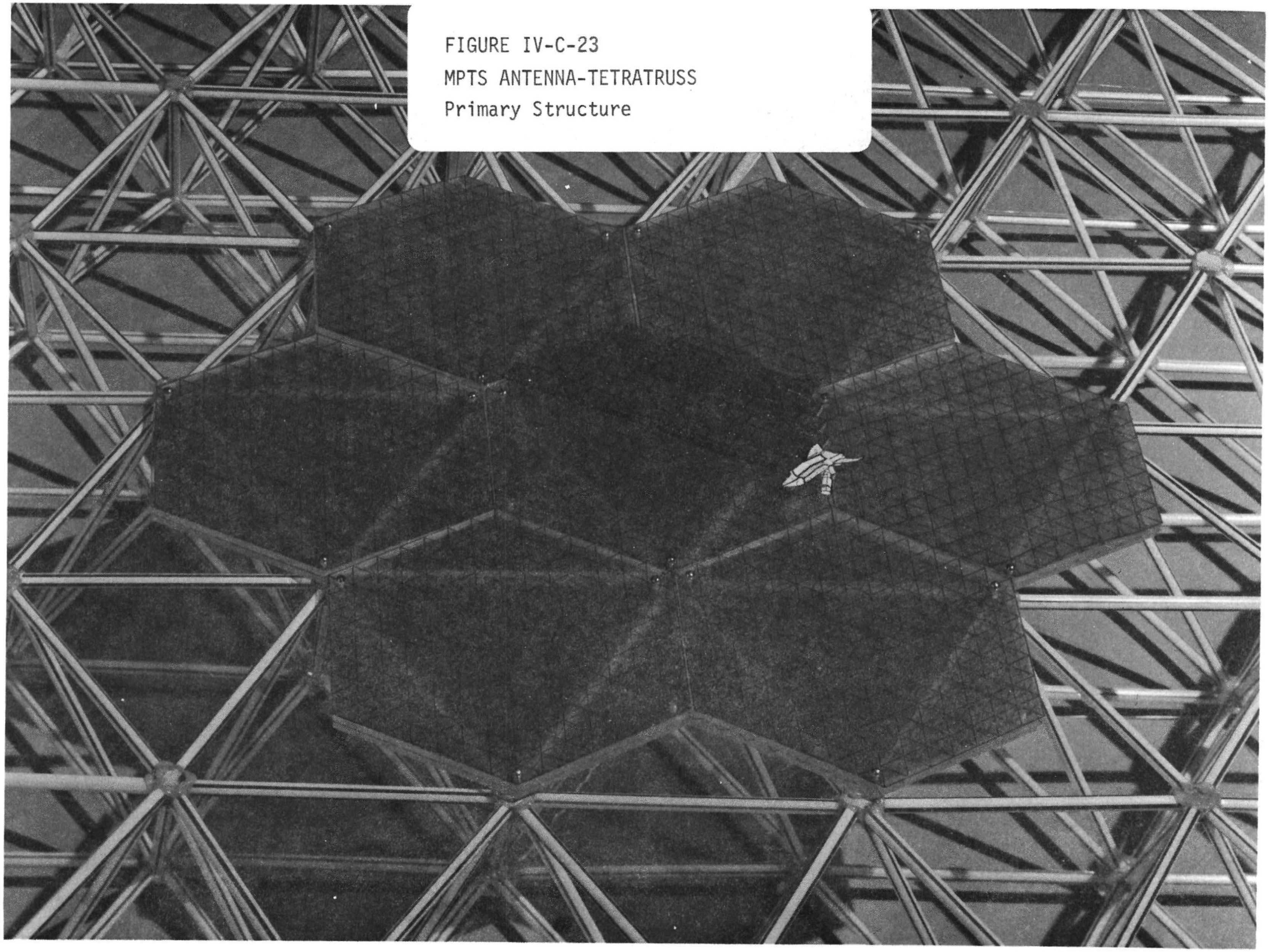


FIGURE IV-C-23
MPTS ANTENNA-TETRATRUSS
Primary Structure

7 5/12/77 MAX-DEF 1 08001750

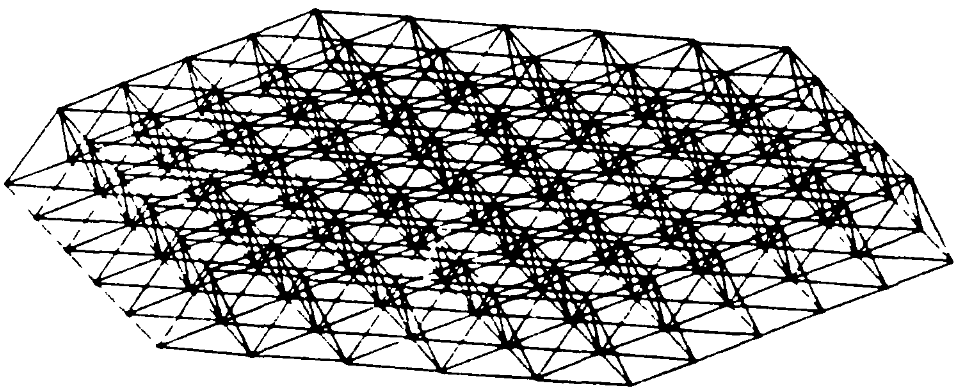
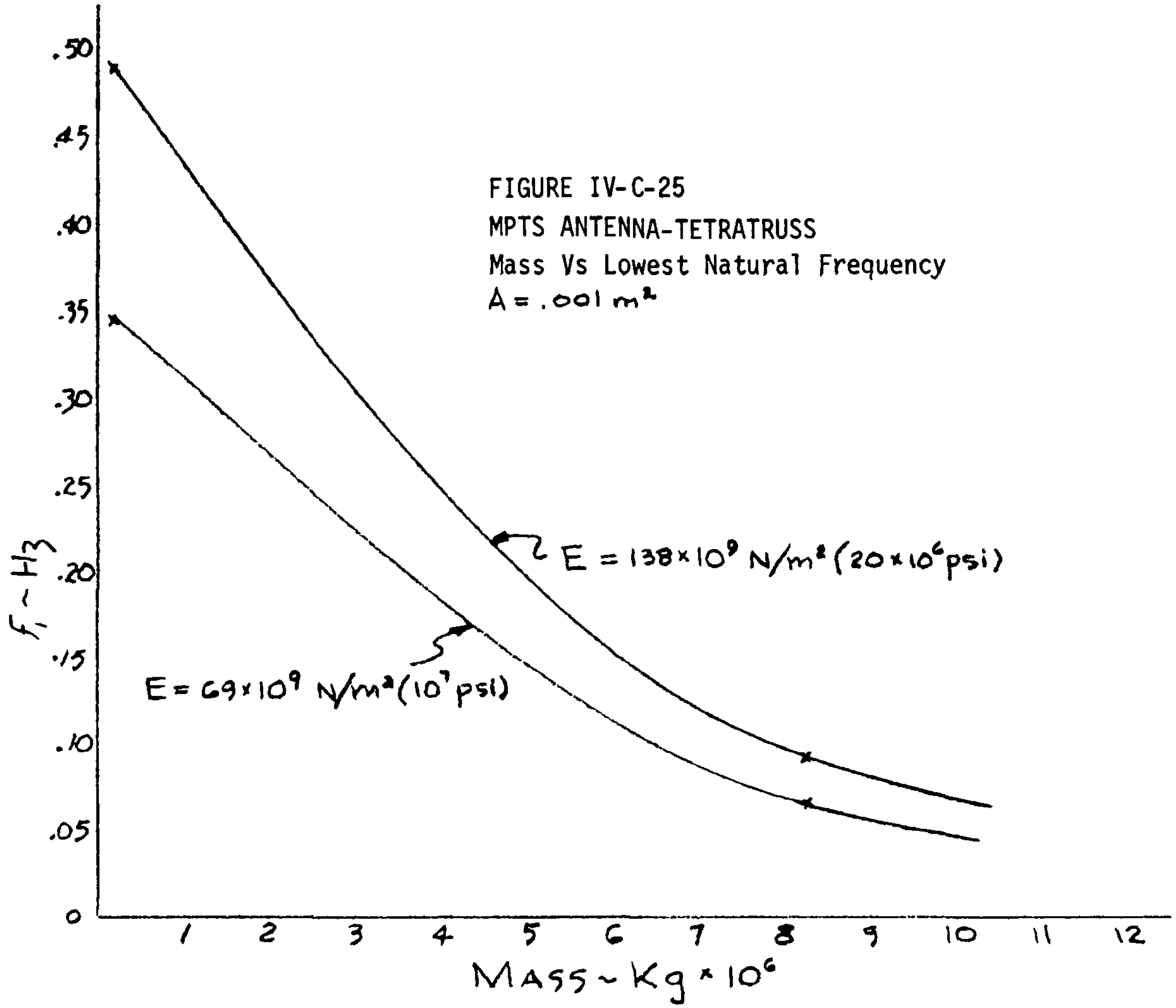


FIGURE IV-C-24
MPTS ANTENNA-TETRATRUSS
NASTRAN model

SATELLITE SOLAR POWER SYSTEM-MICROWAVE ANTENNA TETRA

MODAL DEFOR. SUBCASE 1 MODE 6 FREQ 0 000120

FIGURE IV-C-25
MPTS ANTENNA-TETRATRUSS
Mass Vs Lowest Natural Frequency
A = .001 m²



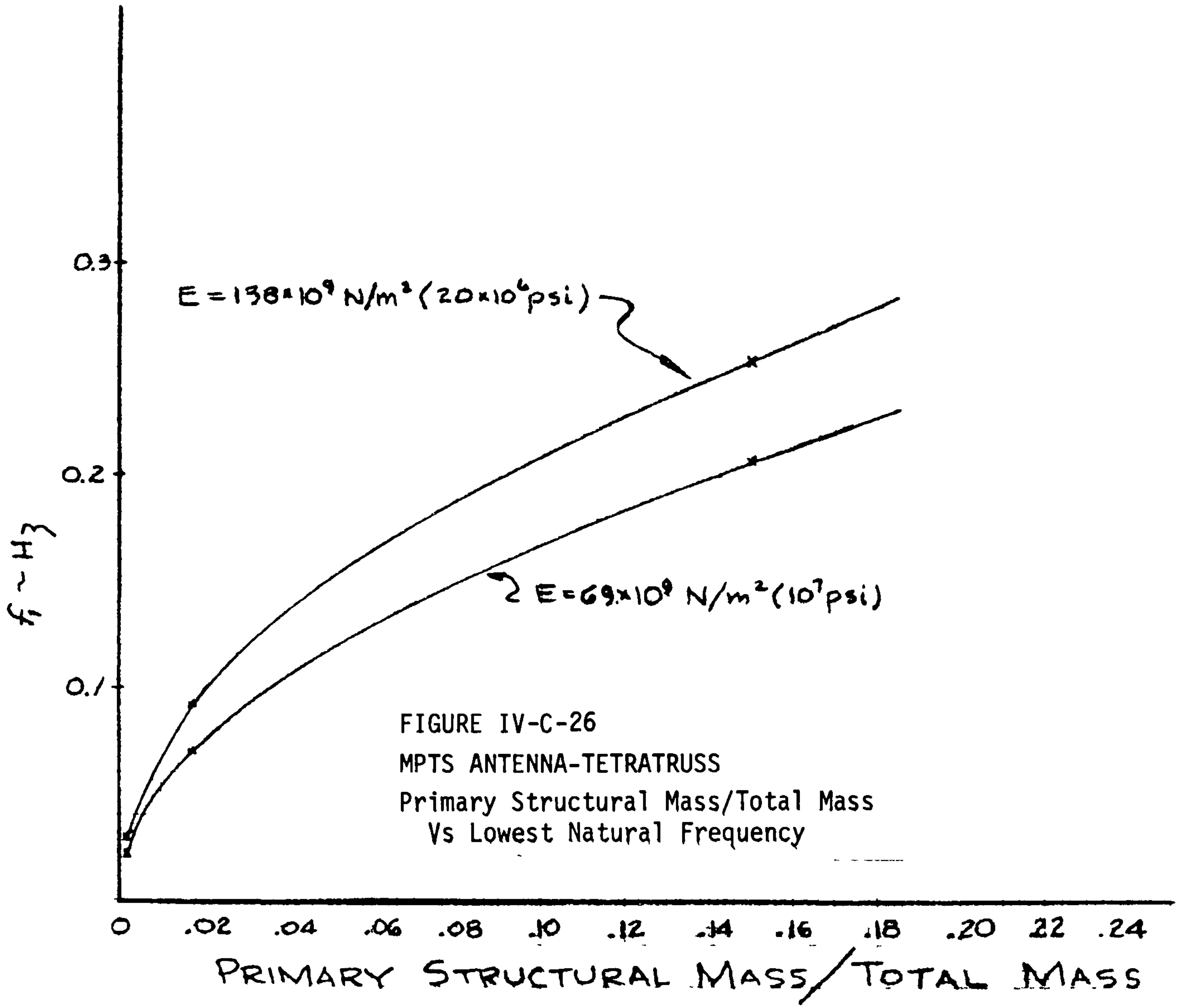


FIGURE IV-C-26

MPTS ANTENNA-TETRATRUSS

Primary Structural Mass/Total Mass Vs Lowest Natural Frequency

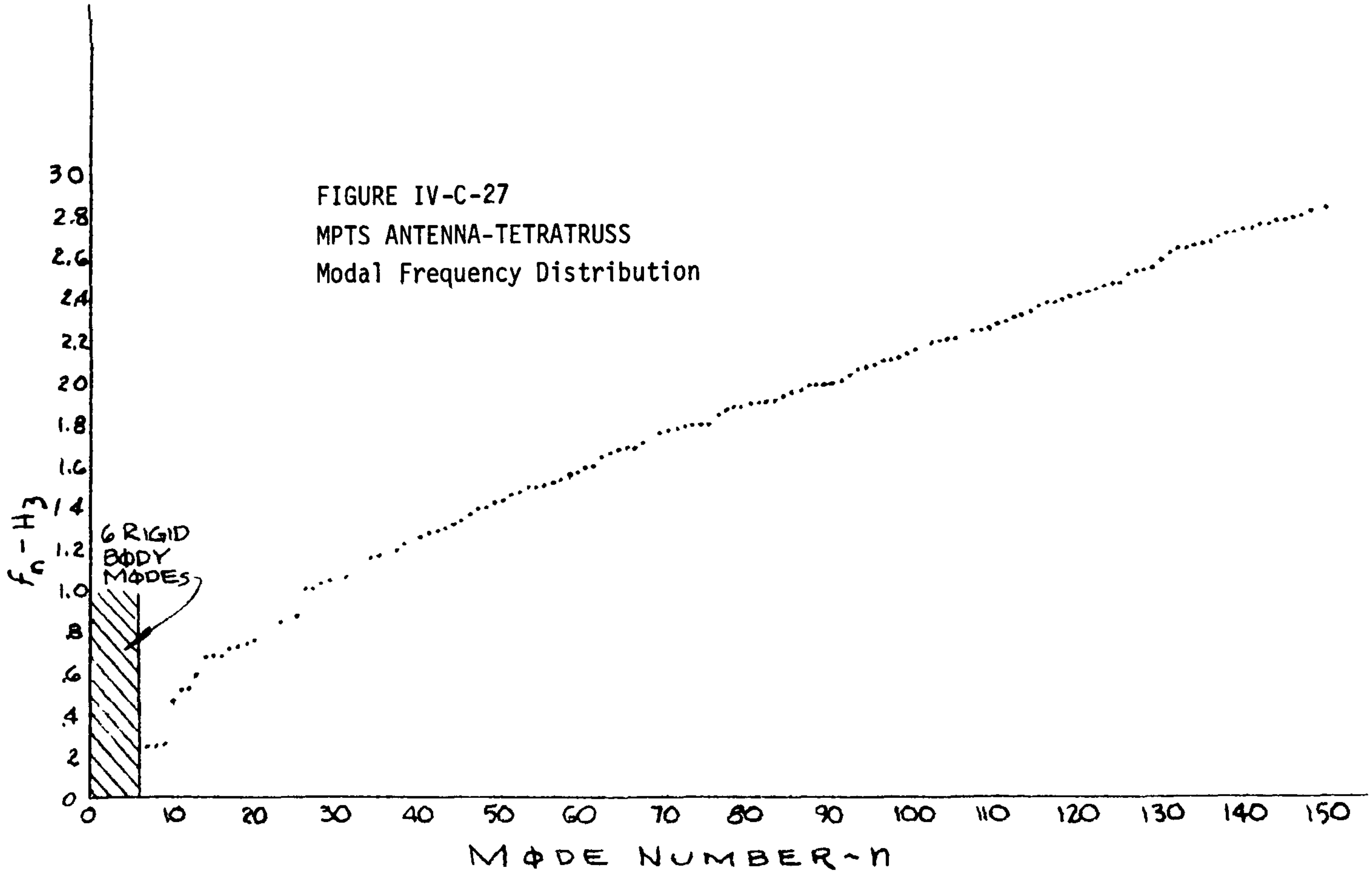


FIGURE IV-C-27
MPTS ANTENNA-TETRATRUSS
Modal Frequency Distribution

24 5/12/77 MAX-DEF 1 18527740

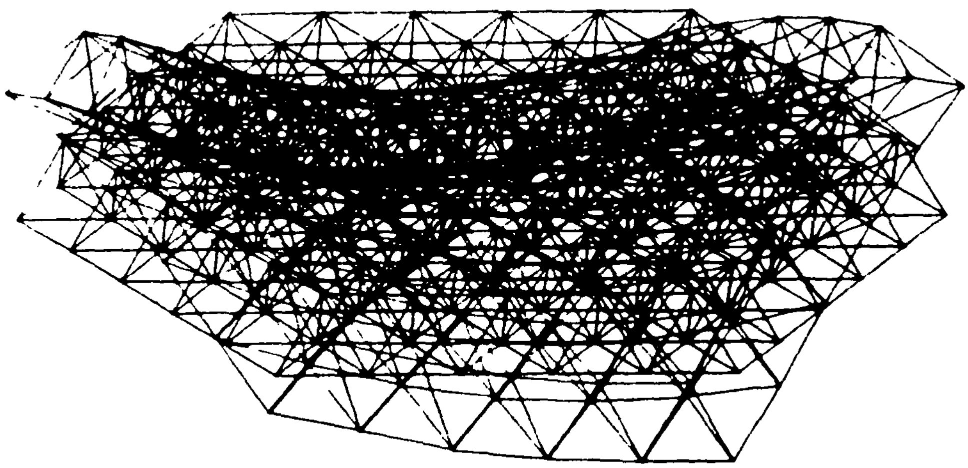


FIGURE IV-C-28
MPTS ANTENNA-TETRATRUSS
Mode 1

SATELLITE SOLAR POWER SYSTEM-MICROWAVE ANTENNA TETRA

MODAL DEFOR. SUBCASE 1 MODE 7 FREQ 0 255237

25 5/12/77 MAX-DEF 1 17803180

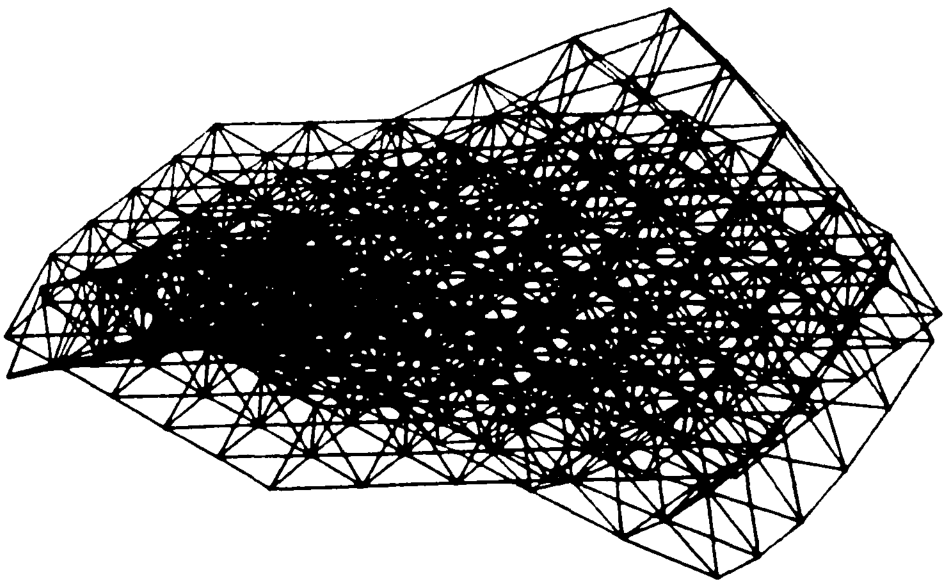


FIGURE IV-C-29
MPTS ANTENNA-TETRATRUSS
Mode 2

SATELLITE SOLAR POWER SYSTEM-MICROWAVE ANTENNA TETRA

MODAL DEFOR. SUBCASE 1 MODE 8 FREQ. 0.256311

26 5/12/77 MAX-DEF 1 14559960

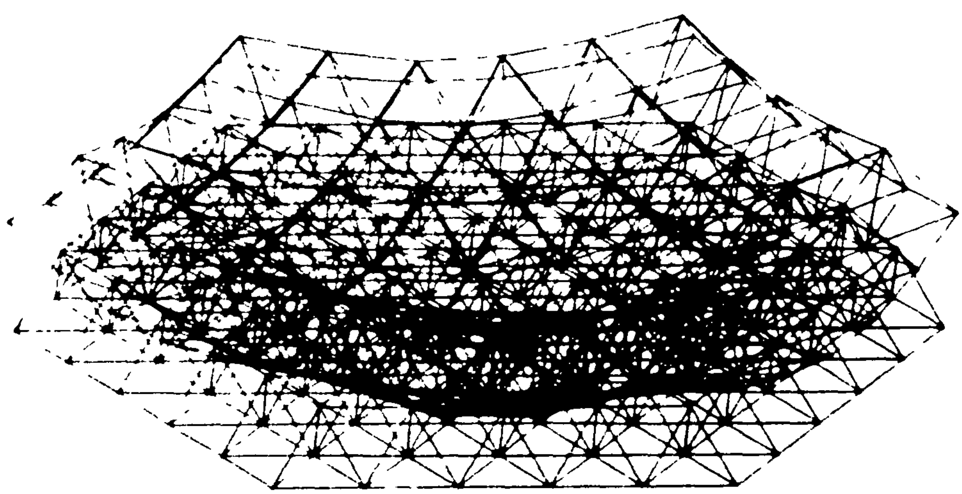


FIGURE IV-C-30
MPTS ANTENNA-TETRATRUSS
Mode 3

SATELLITE SOLAR POWER SYSTEM-MICROWAVE ANTENNA TETRA

MODAL DEFOR. SUBCASE 1 MODE 9 FREQ 0 280276

27 5/12/77 MAX-DEF 1 26613050

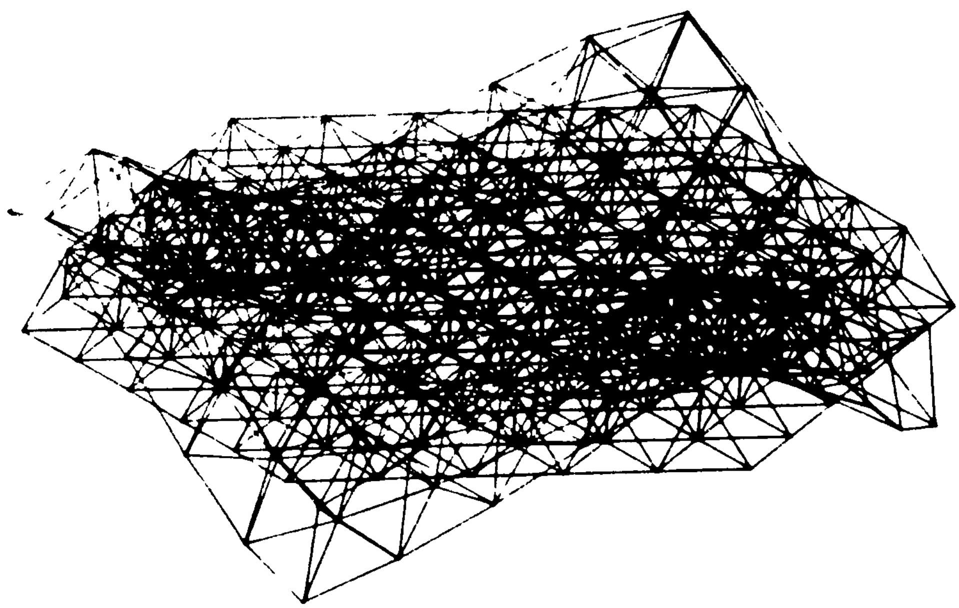


FIGURE IV-C-31
MPTS ANTENNA-TETRATRUSS
Mode 4

SATELLITE SOLAR POWER SYSTEM-MICROWAVE ANTENNA TETRA

MODAL DEFOR SUBCASE 1 MODE 10 FREQ 0 459516

28 5/12/77 MAX-DEF 1 24671`4?

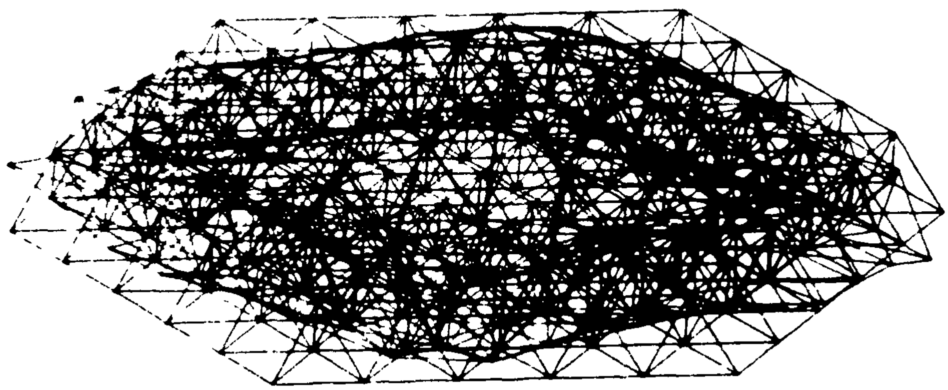


FIGURE IV-C-32
MPTS ANTENNA-TETRATRUSS
Mode 5

SATELLITE SOLAR POWER SYSTEM-MICROWAVE ANTENNA TETRA

MODAL DEFOR SUBCASE 1 MODE 11 FREQ 0 516382

C. Microwave Power Transmission System (MPTS)

4. Thermal Analysis of Klystrons and Amplitrons

Large quantities of waste heat are generated due to inefficiencies of the microwave generators, either klystrons or amplitrons. This waste heat must be dissipated to space using thermal radiators in order to maintain microwave generator temperatures at acceptable levels. A preliminary parametric analysis was conducted to establish radiator weight requirements for various levels of microwave generator output power and efficiency. In this analysis, pyrolytic graphite was used as the radiator material because of its low ratio of density to thermal conductivity. A comparison of klystron radiator weight requirements was made for passive radiators and heat pipe radiators for the configuration shown in figure IV-C-33, rather than the circular radiator configuration shown in figure IV-C-34, which has been used in previous klystron thermal evaluations. For the klystron, it was assumed that half of the waste heat is dissipated in the klystron tube, with the remaining half dissipated in the collector. The radiator base temperature used to establish size and weight was 573°K for the klystron tube and 973°K for the collector.

The results of the klystron parametric analysis are shown in figures IV-C-35. Figure IV-C-35 shows klystron tube passive radiator weight as a function of klystron output power and efficiency, and klystron tube radiator weight requirements for comparable configuration and waste heat dissipation using heat pipe radiators.

Figure IV-C-36 presents a comparison of amplitron radiator weight requirements with required klystron radiator weights for comparable output power, using passive radiators in both cases. The passive radiator weight requirements for amplitrons are those calculated by the Raytheon Company for their microwave power transmission system studies. Amplitron and klystron efficiency used for this comparison was 85 percent. The amplitron configuration used in the Raytheon analysis is shown in figure IV-C-37.

As can be seen from figure IV-C-35, the potential weight saving that can be realized using heat pipe radiators is quite significant except in the case of low-power, high-efficiency klystrons. With the 50 KW, 85 percent efficiency klystron, the radiator weight for a passive configuration is about 15 times that of the heat pipe radiator. However, the total radiator area required is comparable. The power densities using this size and efficiency klystron are 32 KW/m^2 for the heat pipe radiator and 26 KW/m^2 for the passive radiator.

The comparison of passive radiator weights depicted in figure IV-C-36 shows a significant weight difference between the amplitron and klystron radiators. However, it should be pointed out that this is a preliminary assessment of the klystron radiator requirements. The weights shown for the klystron may be larger because of structural stiffness requirements. Additionally, the klystron weights do not include the weight necessary for structural attachments, which will

further increase the total weight. However, the results of this analysis indicate that the weight of a rectangular radiator will be less than that of a circular radiator at the same temperature. For example, the 50 KW, 85 percent efficiency klystron requires passive radiator weight of 1.0 Kg/KW with the rectangular configuration and 1.6 Kg/KW with the circular configuration. The amplitron radiator weight shown can probably be reduced by using heat pipe radiators, at least for amplitrons with an output of 10 KW or higher. A further effort is planned to assess klystron radiator weights more accurately and to determine if heat pipe radiators for amplitrons would be advantageous over passive radiators. A more detailed assessment of heat pipe requirements is also planned, including a review of heat pipe materials and fluids. Although this analysis has shown significant potential weight savings using heat pipe radiators, it should be noted that there are many potential problems with heat pipes which have not been addressed. Among these are potential re-start problems following eclipse periods and the lifetime of 30 years which would be required of the heat pipes. Therefore, much evaluation of the use of heat pipes in this application is required prior to incorporating the heat pipe radiator in the design.

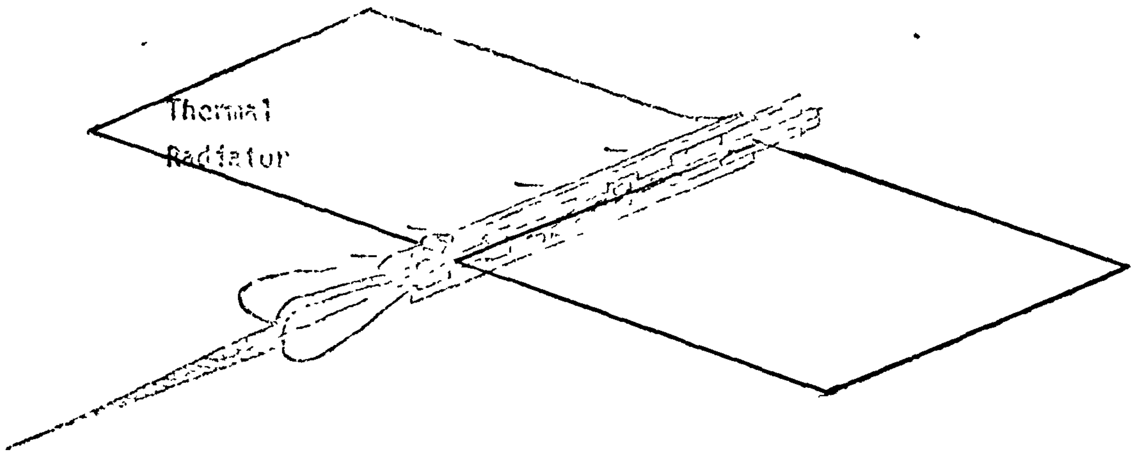


Figure IV-C-33 Klystron in rectangular radiator configuration

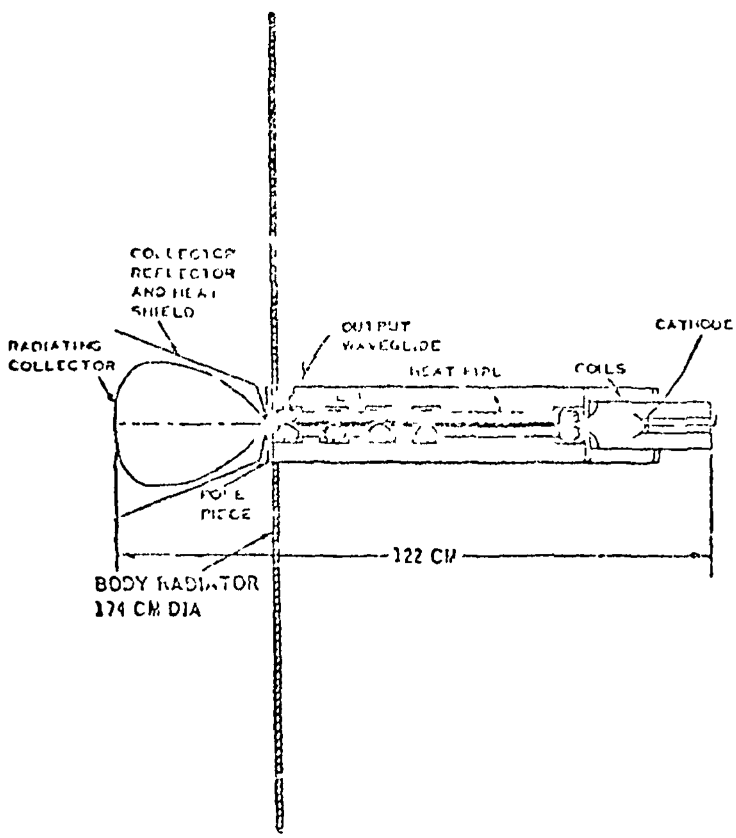


Figure IV-C-34 Klystron in circular radiator configuration

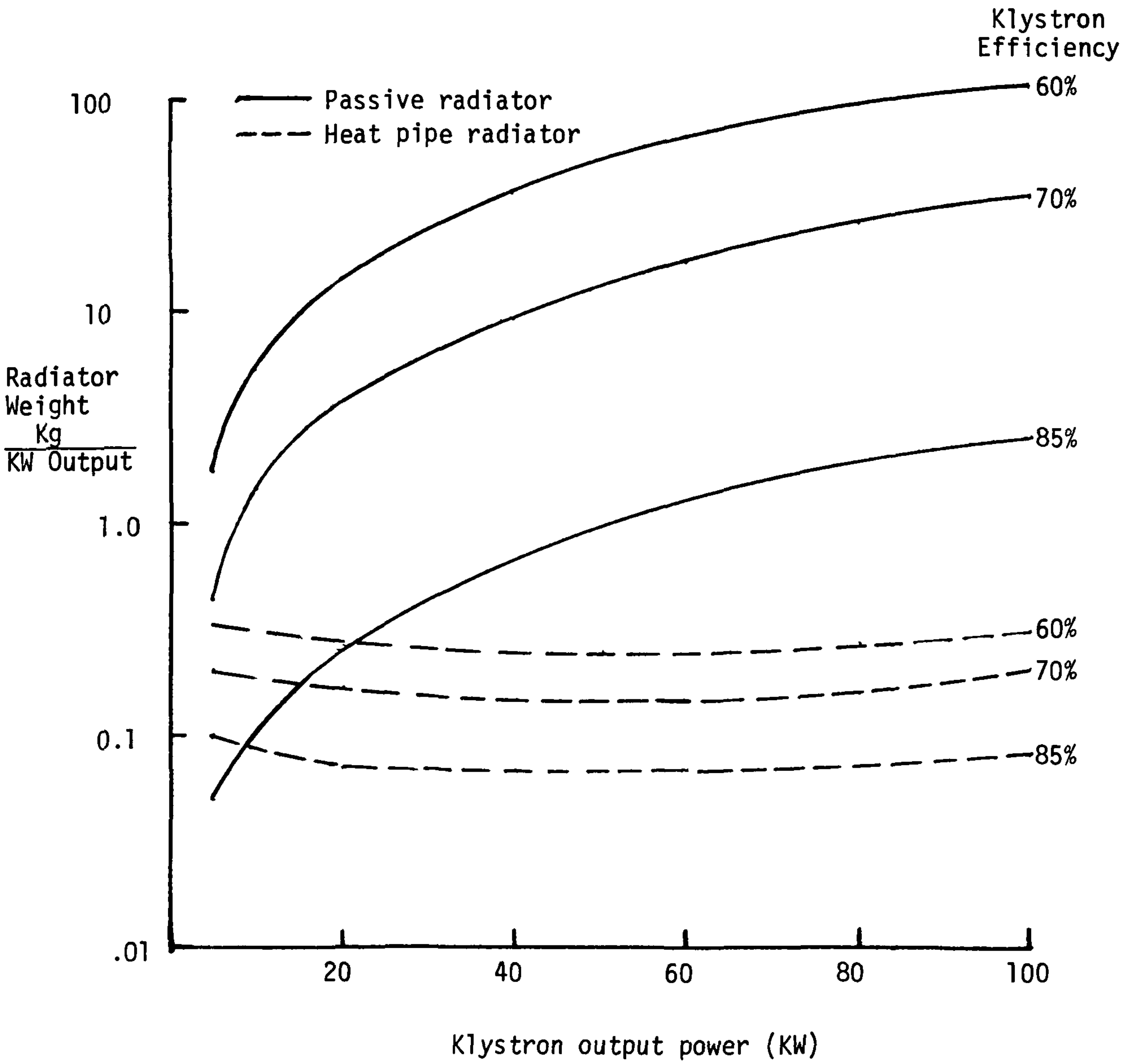


Figure IV-C-35. Radiator weight required for dissipation of klystron tube waste heat as a function of output power and efficiency.

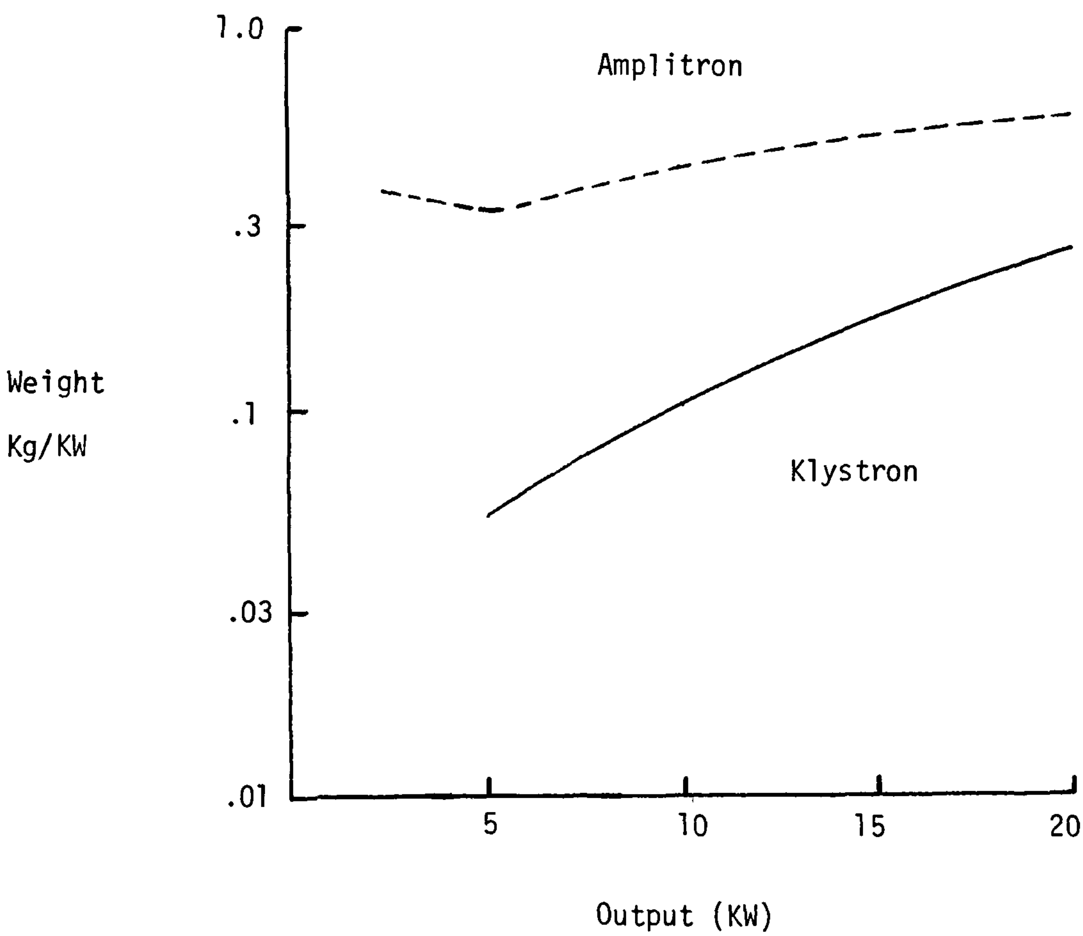


Figure IV-C-36. Comparison of klystron and amplitron radiator weight for 85 percent efficiency.

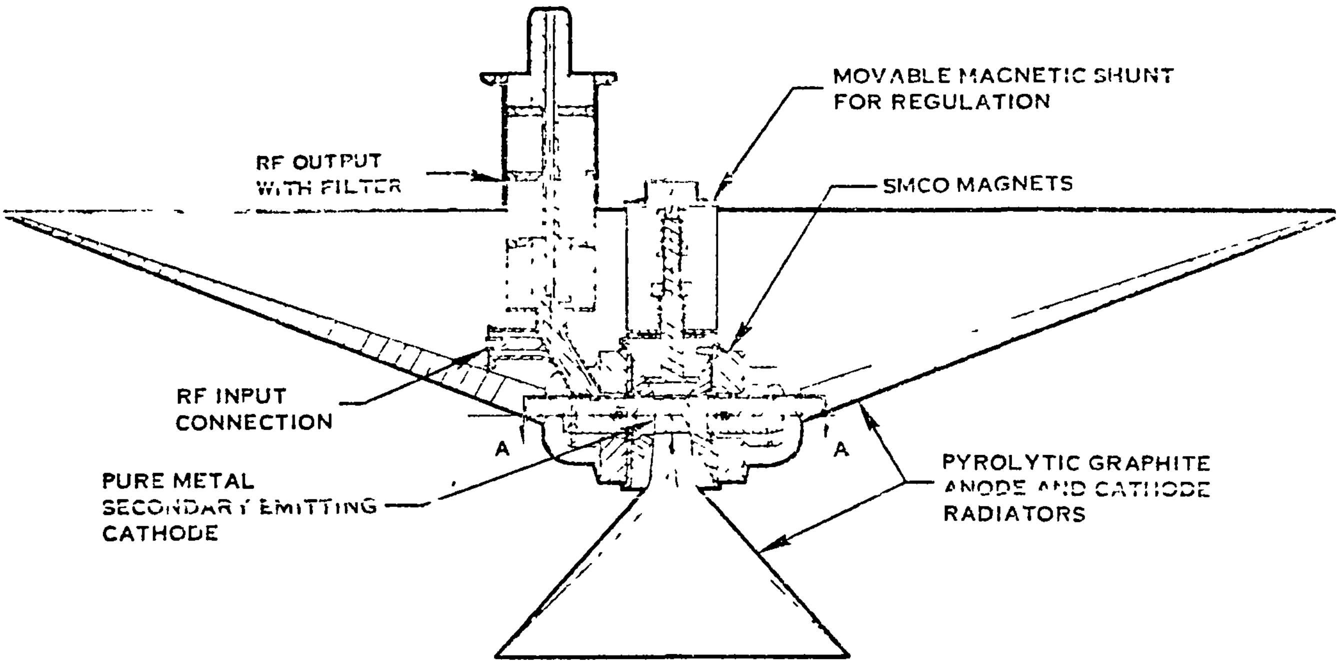


Figure IV-C-37. Amplitron radiator configuration.

IV. POWER STATION

IV-D. MICROWAVE RECEPTION AND CONVERSION SYSTEM

The study of the microwave reception and conversion system (rectenna) has been divided into three areas: 1.) Rectenna Power Collection 2.) Grid Interface, and 3.) Structural Support and Ground Preparation. A summary of the activities to-date are presented in the following subsections.

IV-D-1. Rectenna Power Collection

E. G. Monford
Systems Evaluation Off.

INTRODUCTION

The Rectenna Power Collection of the Component "Rectenna" is that portion of the Microwave Power Transmission System, located on the earth, which collects microwave energy and converts it into power. This system may be subdivided into three areas: 1.) Microwave Conversion Systems 2.) Sixty Hertz Components 3.) Wiring. This section deals with current activity in this area as it effects rectenna size and costs.

PURPOSE

The purpose of this effort is to investigate variations of rectenna size and design; to quickly determine the cost impact of these variations and possible critical material reduction. A computer routine for Rectenna Power Collection (RPC) was written to aid in this analysis because of the complexity involved in hand computations with the large number of variables involved. The "Cost of Power from Satellites" (COPS) program was modified slightly to utilize the output data from the RPC routine for costing analysis. Specific goals of this initial effort were: a short term investigation of the overall cost impact of changing rectenna area and incident power per row.

APPROACH

Briefly, the RPC program calculates the amount of power incident on a row by row basis and the total incident power for a given specific system design. Then, for the same design, the COPS program computes the cost of electricity in $/KW based on incident power and average values for efficiency in three general area os the rectenna: 1.) collection 2.) conversion 3.) interface. So, by using these two routines, general cost trends for rectenna variations may be established. The values used for efficiencies were generally established from dipole and diode parameters, series and parallel interconnection losses, inverter and transformer efficiencies and distribution losses. They were not subjected to a rigorous computational effort to define exact relationships or exact average values as this level of detail was not initially required.

The RPC program analyzes the rectenna area as though it was in a plane perpendicular to the incident microwave beam. The projected ground area is eliptical in shape, however, the electrical groundplane "face" of each row is normal to the incident beam and arranged so that there is no "shaded area" overlap from one row to the next. Because of this, the incident energy is analyzed on a row-by-row basis as though the rectenna was a continous circular surface normal to the beam.

Inputs into the program include the truncated radius of the microwave beam, the beam taper constant, peak energy density, size of elemental area, and the number of rows. The microwave beam has peak intensity at the rectenna center and tapers exponentially to a minimum value near the edge. In a plane perpendicular to the beam, the power level at a given distance from the beam center may be expressed mathematically in terms of the peak intensity, and a constant, derived from desired beam taper.

PROGRAM DETAILS

The program first computes the distance from beam center to the centroid of the first elemental area (defined as row width times element length). The average power intensity for the unit area is then computed using this distance as the basis. The average intensity times the element size provides the power incident on that unit area. This process is repeated for all elements in a row, then results are summed. Elements with centroids exceeding the truncated beam radius are dropped. Power incident results are printed on a per-row basis, and for the whole rectenna. For on-going evaluations, the rectenna has been divided into 1,000 rows, with an element length of 10 meters, a peak intensity of 23 mw/cm^2 and a 10 db beam taper. The routine actually computes incident power of only one quarter of the beam because of the symmetrical nature of the rectenna. The expression used for computing the power incident on the j'th element in the i'th row is:

$$P_{ij} = P_o(x)\ (y)e^{-K(r_{ij})^2}$$

where P_o = peak intensity

x = element width

y = row width

K = (.125) beam taper constant

r_{ij} = centroid of elemental area

RESULTS

Figure IV-D-1 presents the incident power results of successive program runs. In these cases, the rectenna radius was changed, but all other parameters were fixed. The incident power is actually the portion of the beam which could be collected by a 100 percent efficient rectenna of a given radius. Figure IV-D-2 is a plot of the current-per-row output

for a single case. The radius of this design case is 5 KM and for one-half the rectenna there are 500 rows, so the current-per-row for a rectenna of eliptical shape could be found from this same chart by counting the row number from rectenna centroid and using this as the distance (scale factor times one hundred).

Percent total power incident versus percent total area where the 5 KM radius case is 100 percent is plotted in figure IV-D-3. It is interesting to note that a twenty percent area increase is required to capture only four percent more power for the design case.

Figure IV-D-4 presents results of several runs of the COPS routine; it shows the result on the overall SPS power cost in Mills/KWH for various rectenna areas (expressed in percent total area). The design case appears to be at the knee of the curve, where power produced cost is the least. This curve knee will shift as a functional rectenna cost and efficiency of operation. As the cost goes up and the actual efficiency of various components goes down -- a function of distance from the center, the optimum cost knee should move towards 90 percent of the present design case. It should be noted that rectenna costs do not affect the overall SPS costs a great deal until the area is greatly reduced or until the rectenna efficiency drops off significantly. A rectenna with only 60 percent total area still receives 84 percent of the total possible power (96% at design case area).

CONCLUSION

The Rectenna Power Collection Program may be used to support SPS costing efforts and to assist in rectenna design. This program should be refined to include all elements which effect the operating efficiency of the rectenna. The program could then be used to generate power produced by the rectenna (as delivered to the grid), conductor weights and refined cost evaluation.

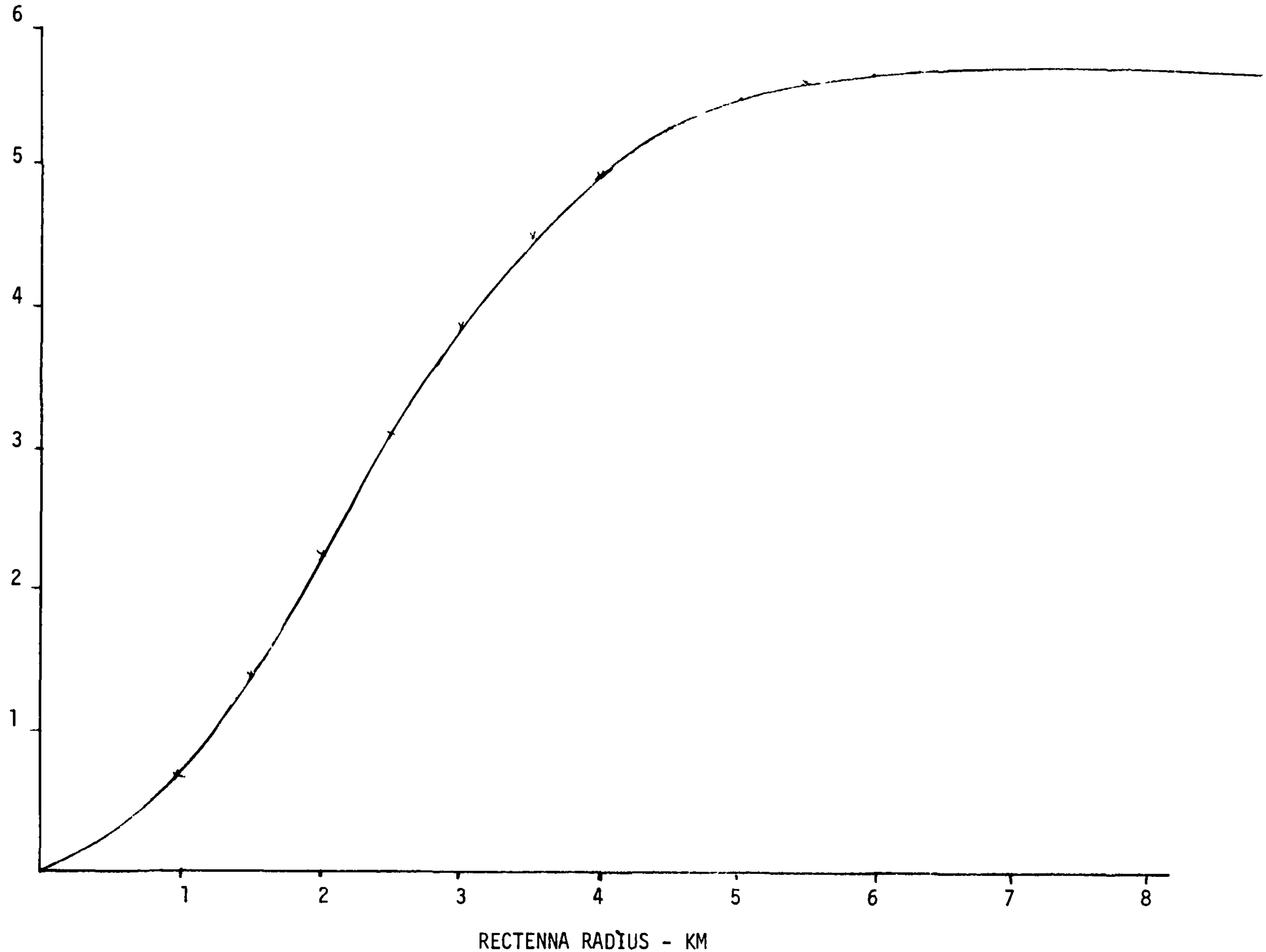
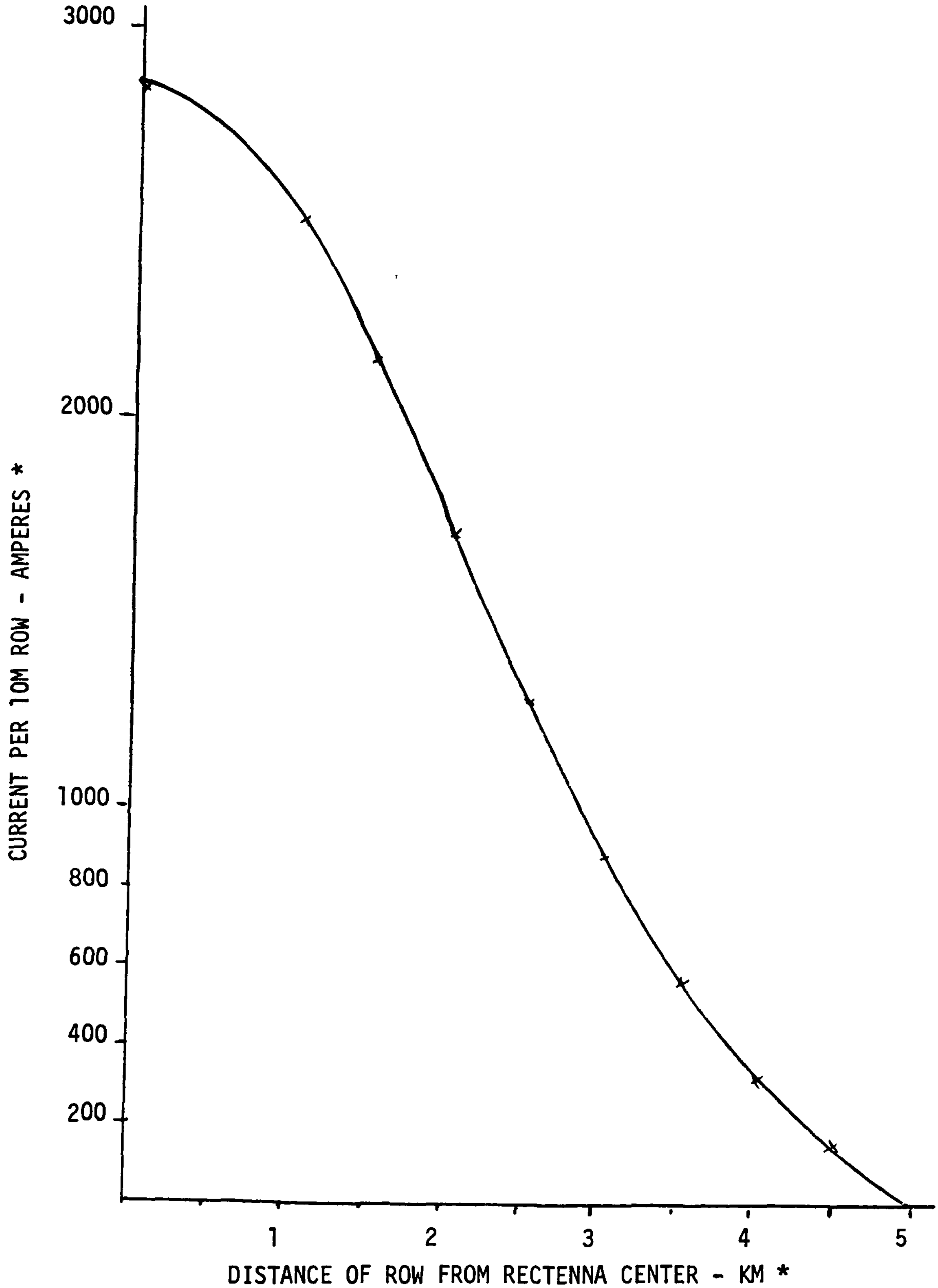
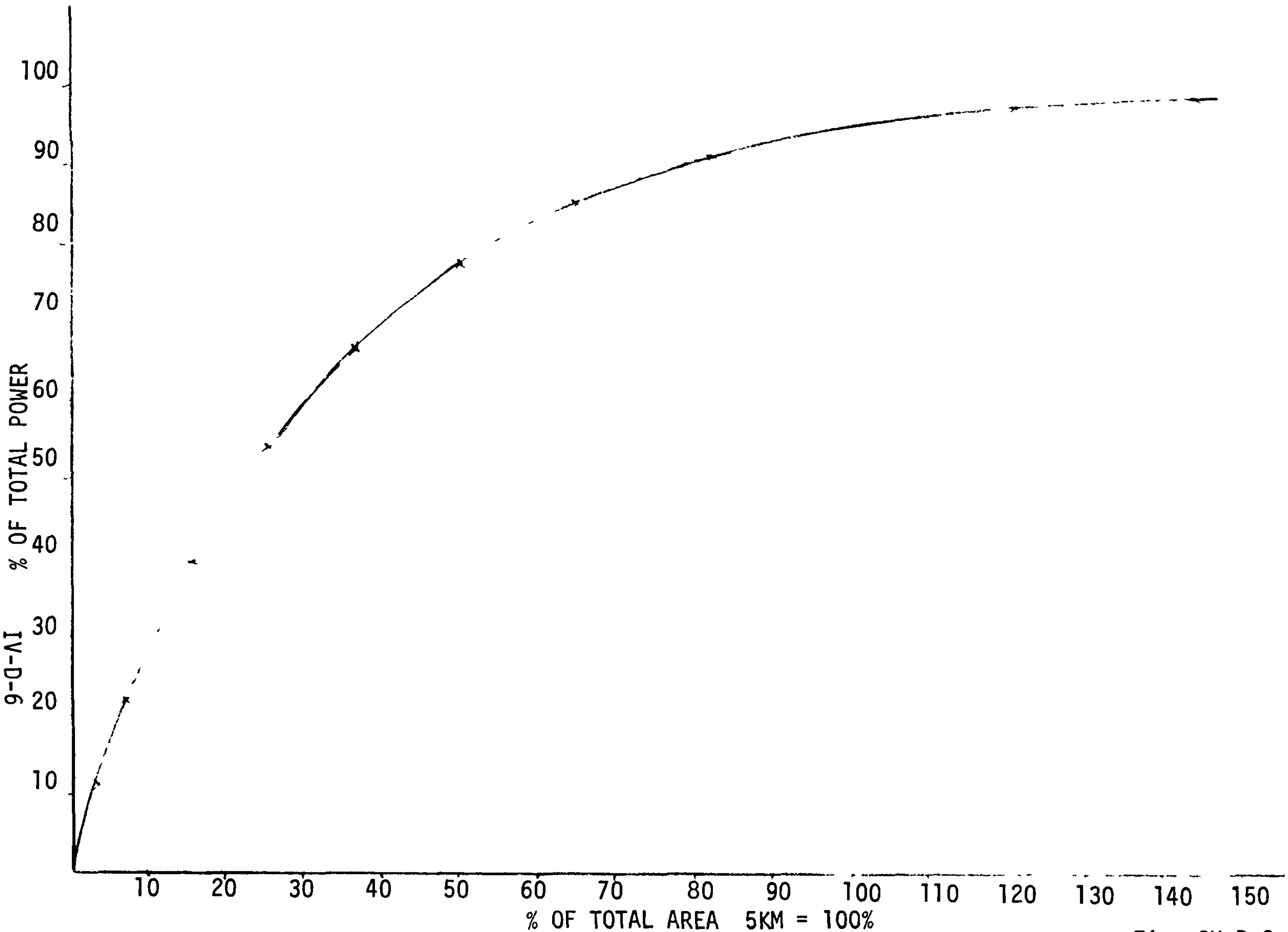


Fig. IV-D-1



*Assuming rectenna is circular with 5KM dia. and 2000 V distribution

Fig. IV-D-2



% OF TOTAL POWER
100
90
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
% OF TOTAL AREA 5KM = 100%

Fig. IV-D-3

SPS COST - MILLS/KWH
VS.
% TOTAL RECTENNA AREA

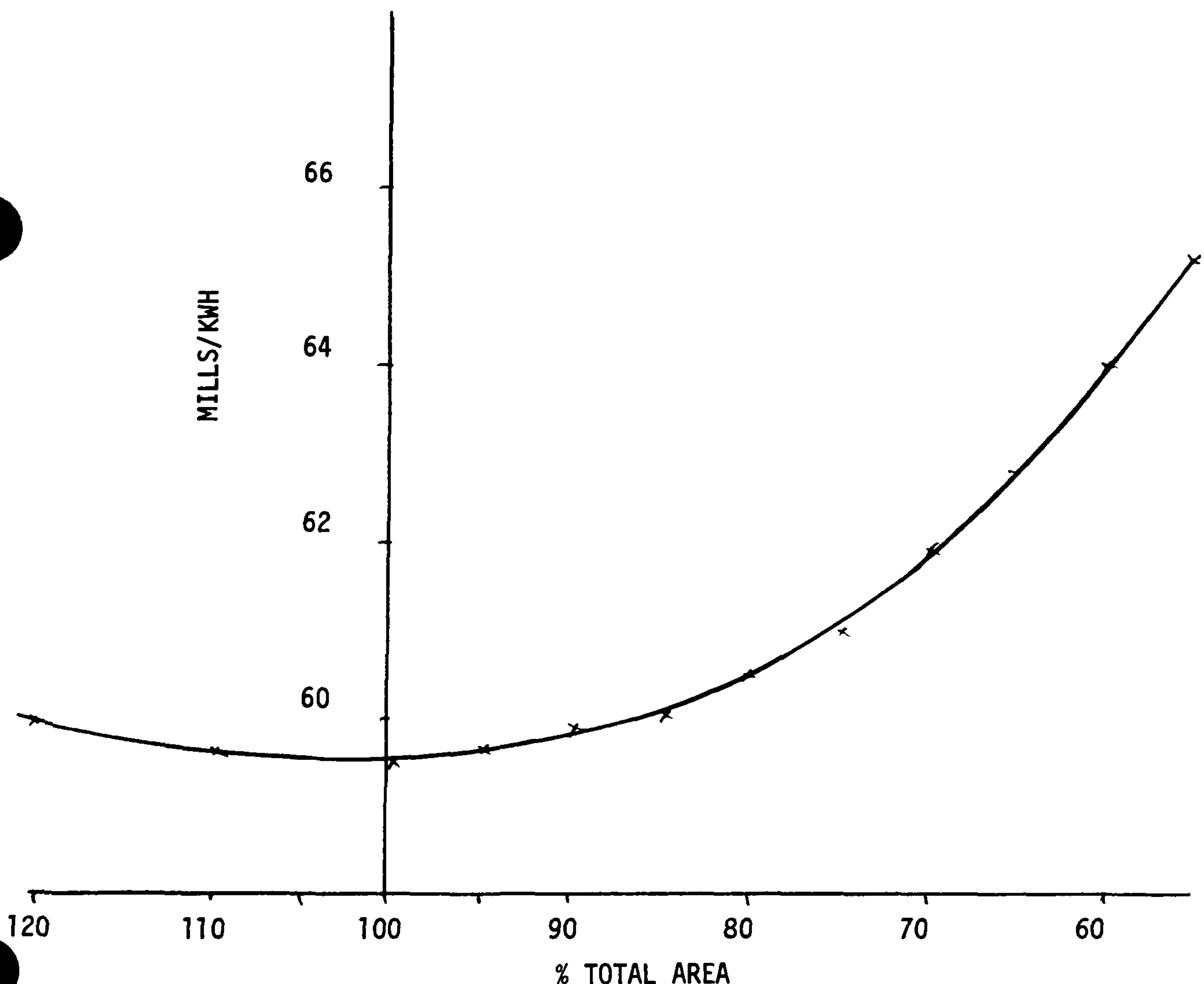


Fig. IV-D-4

IV-D-2 Grid Interface

V. Shields
Systems Evaluation Off.

INTRODUCTION

The ground system/grid interface report published in the "Greenbook" identified methods of collecting power at the rectenna and converting it into electrical energy for transmission to the electrical utility grids. Since that time, we have addressed the issues and problems associated with defining a compatible interface between the rectenna and the infra-structure of the utility grid system. In order to achieve a workable interface, the dominant parameters affecting the rectenna/utility grid were identified and evaluated. Stating the groundrule: "The rectenna/utility interface does not change the reliability of electrical service to its customers;" the following parameters are considered to be the primary technical factors for operating 5.0 GW rectenna systems with the grids.

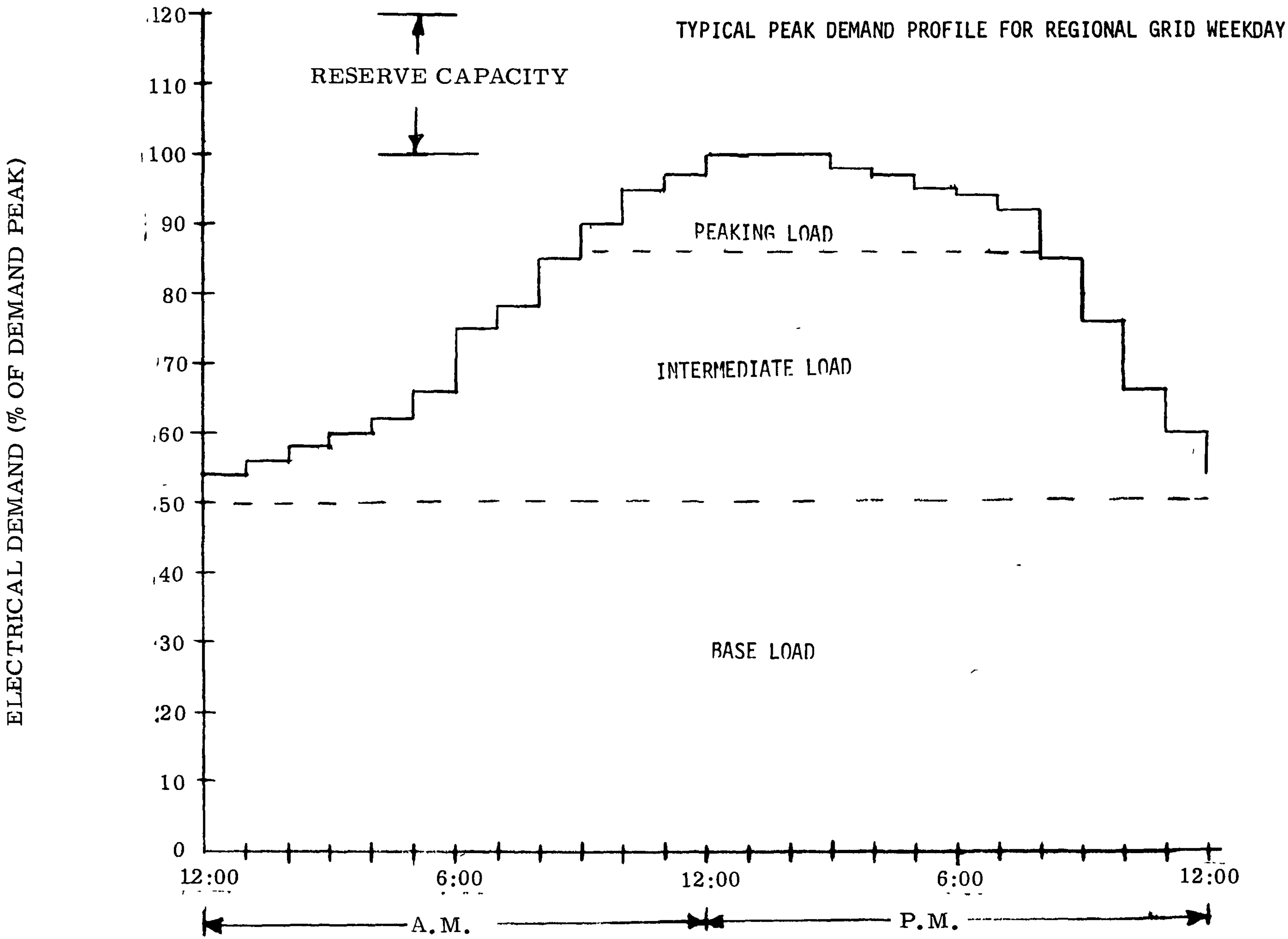
- o The daily and seasonal demand profiles of the grid.
- o The throttling range of the generating machines on the grid.
- o Eclipses of the solar collectors by the earth at the vernal and autumnal equinoxes.
- o Eclipses of the solar collectors by other SPS's at the vernal and the autumnal equinoxes.

Effect of Daily and Seasonal Demand of Utility Grid

Under normal conditions, the consumer demand for electrical power varies over a wide range on a daily, as well as a seasonal, basis. On a daily basis, the peak demand for a weekday is twice the minimum for a typical regional grid (see fig. IV-D-5). In addition, the daily peak may vary by a factor of two from minimum seasonal demand to maximum (see fig. IV-D-6). Therefore, the annual demand spread may be from 25 percent of maximum to maximum annual demand. These factors affect the type, size, and number of machines used to meet the varying grid loads. Depending on size and throttle range, grid machines are selected to serve base load, intermediate load, and peaking load roles. Generally, the larger machines serve base load requirements. The smaller machines are used for peaking and the intermediate size falling somewhere in between.

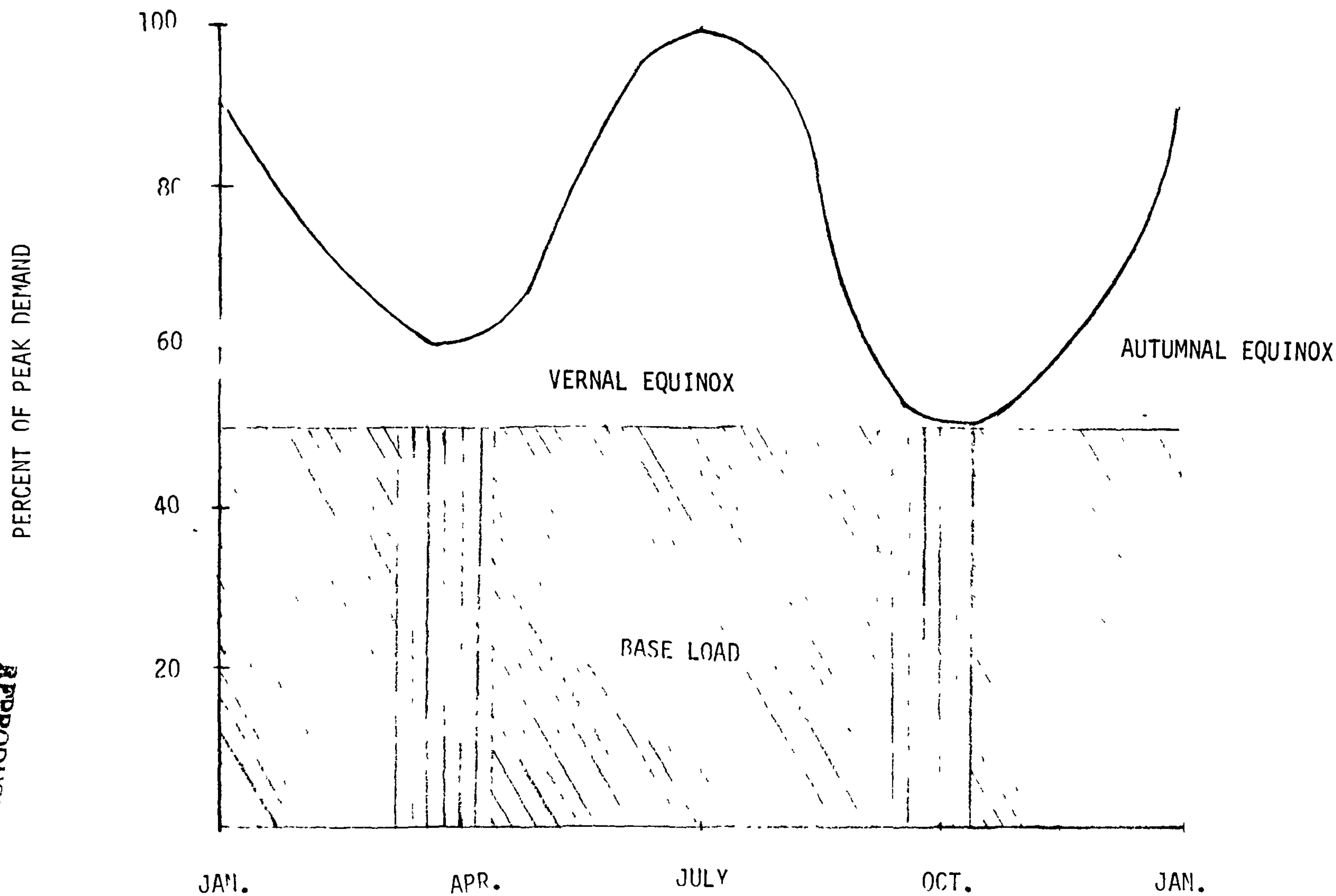
Structures of Installed Generating Capacity of U. S.

The vast majority (over 99 percent) of the installed generation capacity in the continental United States is interconnected in a maize of discrete transmission and distribution networks, referred to as regional grids. There are nine of these regions which collectively make-up the "National Electric Reliability Council (NERC)." This body was founded in 1968 with the stated purpose of augmenting the reliability and adeaquacy of bulk power in the electric utility systems of North America. In order to meet the stated purpose, the Council is primarily concerned with:



TYPICAL PEAK DEMAND PROFILE FOR REGIONAL GRID WEEKDAY
RESERVE CAPACITY
PEAKING LOAD
INTERMEDIATE LOAD
BASE LOAD
ELECTRICAL DEMAND (% OF DEMAND PEAK)
120
110
100
90
80
70
60
50
40
30
20
10
0
12:00
6:00
12:00
6:00
12:00
A.M.
P.M.

Fig. IV-D-5



TYPICAL SEASONAL DEMAND FOR HL&P GRID

Fig. IV-D-6

- o Annual residential and commercial load growth trends.
- o Load forecasts.
- o Timely installation of new generating capacity.
- o Properly coordinating transmission networks.
- o Fuels availability.
- o Financial constraints.
- o Licensing and siting procedures.
- o Government policies and restrictions.

The grid operators or power companies actually own and operate the equipment. In its July 1976 annual report, the NERC presented its projection of load growth, new capacity requirements, etc., through the year 1985. These data and others have been used to show the U.S. generating capacity for 1985 and the year 2025, for the purpose of evaluating the grids for compatibility with solar power satellite rectenna systems in the 2000-2025 time frame. These projections are given in Table IV-D-1.

Utilization of Rectenna Systems on Utility Grids

Initial studies of the SPS indicate that the rectenna be sized near 5.0 GW output for optimum economic return. Using that assumption, this study is aimed at determining the impact modular power sources of that size have on the operation of the regional grids. Due to its size (5.0 GW) the rectenna would serve as a base load generator. The method of operation would be to collect the DC power along busses within the rectenna, convert it to AC through thyristor or SCR inverters using grid power to fire the inverter elements, thus achieving and maintaining synchronous operation with the grid. In the case of the SPS, the rectenna would be shutdown daily for short periods of time near 12:00 a.m., for 45-days around each equinox. This is brought about due to an eclipse of the SPS collector with the earth at the vernal and autumnal equinoxes for a geosynchronous orbit. Also, if Scenario "B" of the Greenbook were carried out, with 112 satellites in geosynchronous orbit in the year 2025, the solar collectors of each satellite would eclipse each other on a daily basis at 6:00 p.m. and 6:00 a.m. for a 45-day period around each equinox. Outages of this types are unknown in the existing grid operating structure, requiring new methods of power management. The variables that primarily affect the total number of rectenna that may operate on a single grid are:

- o Installed capacity.
  - o Conventional machinery.
  - o Rectenna systems.
- o Reserve margin requirements.
- o Peak demand.
- o Throttle range of conventional machines.

TABLE IV-D-1

U. S. INSTALLED GENERATING CAPACITY

BY FUEL SOURCE

(3.4% ANNUAL GROWTH RATE)

GENERATION TYPE	INSTALLED CAPACITY (GW)		PERCENT OF TOTAL	
	1985	2025	1985	2025
NUCLEAR	173.9	3495	21.8	61.5
COAL	320.5	1615.4	40.2	28.5
HYDRO	85.0	291.2	10.6	5.2
OIL	167.1	198	21.0	3.5
GAS	45.5	74.6	5.7	1.3
OTHER	5.8	----	.7	----
			100	100

YEAR	AVERAGE THROTTLE RANGE
1985	39.5% OF FULL-LOAD TO FULL LOAD
2025	64.2% OF FULL-LOAD TO FULL-LOAD

The installed capacity represents the rated output (KW) of the combined generators connected on the grid. Generally, grid capacity equals to the annual peak demand plus 20 percent, denoted as reserve capacity. From figure IV-D-5, baseload units make-up about 50 percent of grid capacity with the remainder consisting of intermediate load and peaking machines. Usually, baseload machines are large and more efficient than other generators and the grid operator's strategy is to use them as much as possible. This results in a high load factor for this equipment, normally in excess of 0.7.

If SPS rectenna systems replaced existing base-load machines on the utility grids, their load-factor could exceed 90 percent. However, due to the discontinuity of the SPS output around the equinoxes, the management of power on the grid must be changed.

In one case, the outage occurs around mid-night for a 45-day period around each equinox. An outage at this time of day has a minimum impact on grid power management. The reason being, when this outage occurs the grid demand is only about 50 percent of its peak demand. For the period of the outage (fifteen minutes maximum), the demand could be handled by other capacity on the grid. It should be pointed out that the throttling characteristics of the other machines is an important consideration. Just prior to the outage, the rotating equipment will be lightly loaded until a transfer of load from the rectenna system to this equipment can be made. The design of some systems, for economic reasons have very narrow throttling ranges. For example, a nuclear plant may have a range of 90 percent of full-load to full-load, where as a fossil-fired plant may have a range of 30 percent of full-load to full-load. When considering the throttling range of the grid, the throttling characteristic of the combined rotating machines must be determined. This is based on the percentage mix of fossil-fired, nuclear, and hydro-electric powered generators on the grid. Once the grid throttle range, installed capacity, and reserve margin requirement are determined, the following equiation may be used to determine the maximum number of rectenna possible on each regional grid.

$$\text{no. of rectenna} = \frac{IC(1-RM)(1-T_{R\ min.})GW}{5\ \frac{GW}{\text{Rectenna}}}$$

IC - installed capacity
RM - reserve margin
TR - throttle position

For the example shown in Table IV-D-2, the reserve margin was given as 10 percent, and the minimum throttle rage of 64.2%, based on the nuclear, fossil-fired, hydro generation mix projected for the year 2025.

NO. OF 5 GW ALLOWABLE ON EACH
REGIONAL GRID DUE TO ECLIPSES
AT THE EQUINOXES FOR 2025
(NO STORAGE SYSTEM)

$$\text{NO. OF RECTENNA} = \frac{IC(1-RM)(1-TR_{MIN.})GW}{5\ \frac{GW}{RECTENNA}}$$

COUNCIL	INSTALLED CAPACITY (GW)	RESERVE MARGIN(%)	THROTTLE RANGE	NO. OF 5 GW RECTENNA DUE TO TO ECLIPSE OF EARTH	NO. OF 5 GW RECTENNA DUE TO ECLIPSE OF OTHER SPS'S
ECAR	822.5	10	64.2% OF FULL-LOAD TO FULL-LOAD	53	10
MAAC	453.7	↓		29	5
MAIN	470.3	↓		30	5
MARCA	249.6	↓		30	5
NPCC	482.1	↓		16	2
SERC	1225.2	↓		79	13
SWPP	555.9	↓		36	6
WSCC	1009.6	↓		65	11
ERCOT	402.7	↓		26	4
			TOTAL	364	60

IC - INSTALLED CAPACITY

RM - RESERVE MARGIN

TR - THROTTLE POSITION

TABLE IV-D-2

For the case given in scenario B, 112 satellites are in geosynchronous orbit, eclipsing each other at 6;00 a.m. and 6;00 p.m. Utilizing the same technique the number of possible rectenna is reduced because the outage occurs near the daily demand peak, thus reducing the throttling range of the grid. The idea of spreading rectenna power over several grid networks minimizes the effects of losing power at any site. Also, since it is possible to distribute the rectenna power in the form of DC, the direction of flow of power to the grids maybe controlled, with the AC stability of the network being virtually unaffected. If indeed, widespread use of DC blocks of power come into use as a means of interconnecting regional grids, then by the year 2025 we should observe a relative small variation in the hourly demand for electricity on a national scale. Such a power management scheme would virtually eliminate the effects of SPS outages based on the assumptions given in scenario B of the JSC-11568.

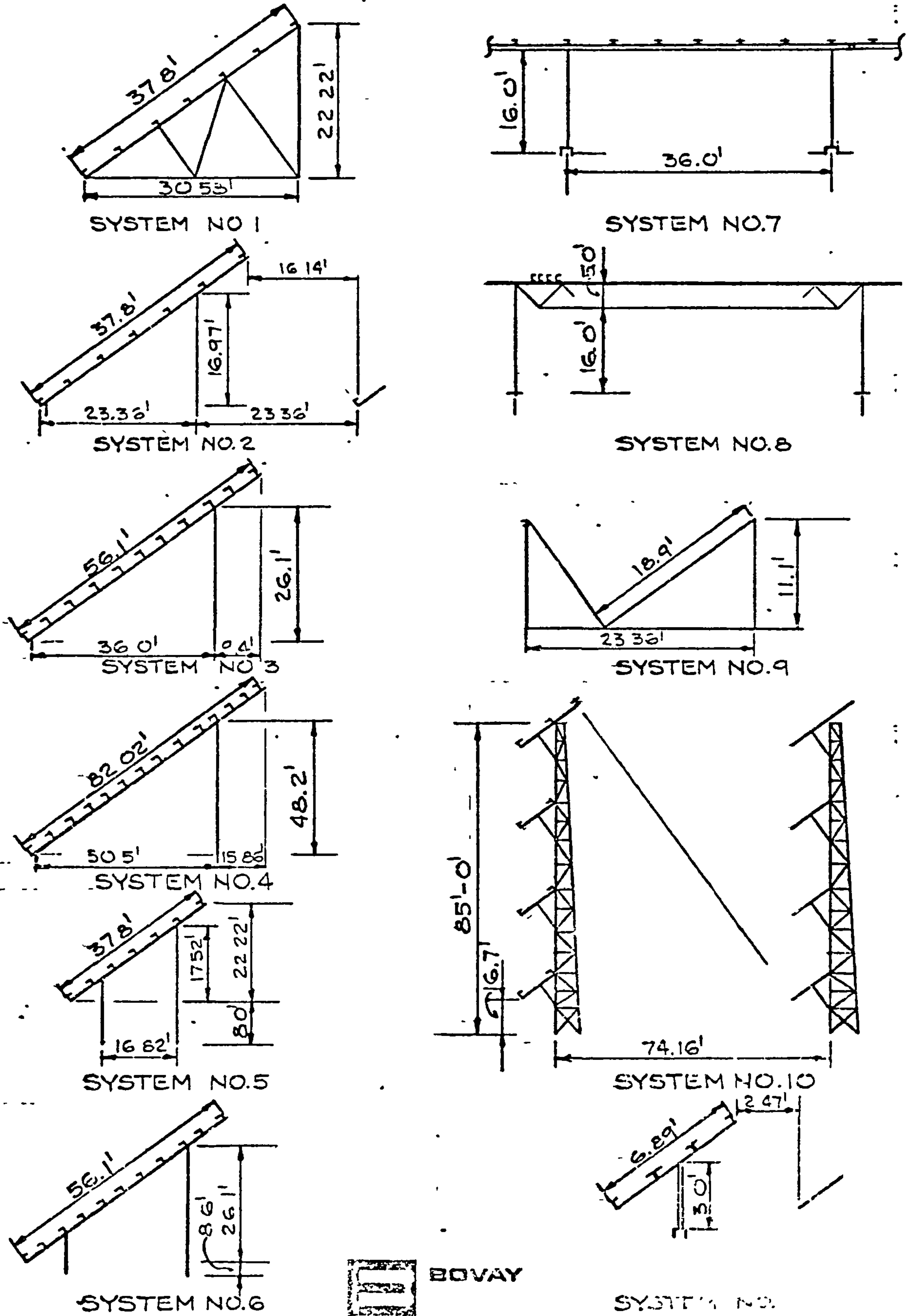
IV-D-3 Structural Support and Ground Preparation

H. Roberts
Systems Evaluation Off.

The support structure for the rectenna concept defined in sections IV-D-1 and IV-D-2 has been investigated through study contract No. NAS9-15280 with Bovay Engineers, Inc. The objective of the study was to study various approaches to the structural design/arrangement of the rectenna and investigate relative merits of the approaches. Each approach to the structural design/arrangement was limited to a design level consistant with determining gross material quantities and projected costs. Included in the designs were considerations of geometry, loadings, cost, maintenance, and materials of construction. The contractor was given study requirements which were to be used as design criteria: (1) The rectenna is to be located 31° latitude which dictates that the 10 kM diameter microwave beam has a 54° angle with the horizontal and the projected ground area covered is eliptical in shape with a major axis of 12.36 kM and minor axis of 10 kM. Also, cost effects will be determined for location at 40° latitude. The rectenna must intercept all of the 10 kM diameter beam. (2) For the initial investigation and analysis, the terrain will be assumed to be flat. However, the effects on costs will be investigated for rolling terrain. (3) Ground surface area covered by the rectenna is required to be usable for other purposes such as crop production. (4) The groundplane will have a pattern of diamond-shaped openings 1 cm by 2 cm and must be electrically conductive. If found to be advantageous, the groundplane may be utilized as part of the structure. (5) The groundplane and the structure must be designed to provide maintainability of the receiving elements. (6) The primary structure must be insulated to 2000 volts, both from the ground and the groundplane.

One of the first tasks in the study was to determine and analyze the environmental loads which would size the structure. After searching through the Uniform Building Code and the Southern Building Code, it was determined that there is no direct guidance in the building codes for developing design loads for a structure similar to the rectenna. However, the principles used in the codes were used to rationalize realistic loadings. Thus, a live load of 12 PSF (pounds per square foot), wind loads from 20 PSF at ground level to 30 PSF at 50 feet elevation, and snow loads of 5 PSF were selected for design and analysis. It was concluded that the wind load could be used as the design load without combining with the live and snow loads. Other loading effects such as seismic and thermal loads were also considered.

The contractor evaluated the 11 structural systems shown in figure IV-D-7. Systems 1 through 6 and 11 have the groundplane segmented into rows with the surface perpendicular to the incoming microwave beam. Systems 1 through 4 and 11 have one edge of each segment on or near the ground, while systems 5 and 6 are elevated to provide clearance below the structure. Systems 7 through 9 are elevated to provide clearance for vehicles or machinery to operate below the structure. Systems 7 and 8



BOVAY

Figure IV-D-7 STRUCTURAL SYSTEMS

have the groundplane perpendicular to the microwave beam, but the width of each segment is small compared to the other systems. System 9 has wide segments, but still provides the greater clearance. System 10 is a series of towers with the groundplane segmented as shown in figure IV-D-7. Each of the systems will have concrete footings poured in place to distribute the loads into the soil and to resist any uplift forces which will occur.

Several materials, including aluminum, steel, concrete, plastics and wood were investigated for their applicability. It was concluded that either galvanized or weathering steel would be the most advantageous material considering all the requirements. Each system will require a portion of the structure to be made from aluminum for power conduction.

Estimates of the materials quantities and costs were made for each system. A summary of these is shown in Tables IV-D-3 and IV-D-4. Also, an estimate was made on the cost of site preparation and is shown in Table IV-D-5. The results of the study show that within a limited space between columns, little cost difference exists between the different configurations. As the usability of the land increases (larger column spacing), the structural cost increases significantly. The geographical location of the rectenna site will have a major impact on both construction and structural costs. At 40° latitude the cost increase would be between 20 percent and 45 percent for the different configurations due to the increased loads at the latitude. The effect on cost for rolling terrain depends on many factors including the magnitude of the elevationvariations. The net cost effect can be between zero and 24 percent. The cost reported in JSC-11568 was $0.60/ft^2 with a range from $0.48/ft^2 to $2.35/ft^2.

The contractor concludes that several areas of further study are needed to refine the numbers they have estimated. These recommendations can be reviewed in the contractors final report.

TABLE IV-D-3: SYSTEM MATERIALS QUANTITIES

SYSTEM #	ALUMINUM (KG X 10^8)	STEEL (KG X 10^9)	CONCRETE (KG X 10^9)
1	1.50 *(6.10)	1.46	1.29 *(1.72)
2	1.50 *(6.68)	1.50	1.29 *(1.72)
3	1.01	1.58	1.91
4	0.69	1.79	2.31
5	1.50	1.49	1.43
6	1.01	1.62	1.91
7	1.45	1.89	1.03
8	1.56	2.82	1.50
9	1.61	1.78	1.16
10	2.79	13.53	1.20
11	----	0.82	1.26

*Note: These numbers represent an all aluminum structure, while all other numbers represent steel structures.

TABLE IV-D-4: SYSTEM COST COMPARISONS

SYSTEM NUMBER	COST PER SQUARE FEET GROUNDPLANE AREA	COST PER SQUARE FEET SHADED AREA	MATERIAL COST (%)	FABRICATION COST (%)	ERECTION COST (%)
1	2.36 *(4.05)	1.91 *(3.28)	35	45	20
2	2.48 *(4.32)	2.00 *(3.49)	40	40	20
3	2.36	1.91	40	40	20
4	2.49	2.01	40	40	20
5	2.47	2.00	40	40	20
6	2.43	1.96	40	40	20
7	----	2.32	40	40	20
8	----	3.06	40	40	20
9	----	7.23	35	45	20
10	4.32	3.51	35	45	20
11	1.79	1.45	40	40	20

*NOTE: These numbers represent an all aluminum structure, while all other numbers represent steel structures.

TABLE IV-D-5: SITE PREPARATION COSTS

Location and Site Condition	Cost/Acre*	Cost/ft^2
Semi - Desert Area; Western States Land - Generally flat, sandy; little or no rock	$1,500	$.03
Gulf Coast or Midwest States; Medium tree cover; Clay or Loam type soil; basically flat area, Rainfall 25" or more per year	$2,700	$.06
Mountainous Location; Rock & Timber; Moderate rain and snow	$4,000	$.09

*COSTS INCLUDE:

- Clearing and Grubbing: Heavy to light (depending on area)
- Grading and Drainage
- Roads: Perimeter and 3 cross roads; 50 miles 24 ft. wide asphalt.
- Culverts: 24" diameter C.M.P.
- Culverts: 60" diameter C.M.P.
- Bridges: 30 ft x 70 ft or 2100 ft^2
- Service Roads: 70 miles, 20' wide, gravel surface
- Service Roads: Drainage Low water type crossing
- Fence around perimeter: 8 ft high, chain link.
- Seeding & Fertilizing

NOTE: Cost does not include utilitites, site survey, operations and maintenance facilities.

W. L. Gill
Systems Evaluation Off.

APPENDIX

Section IV.

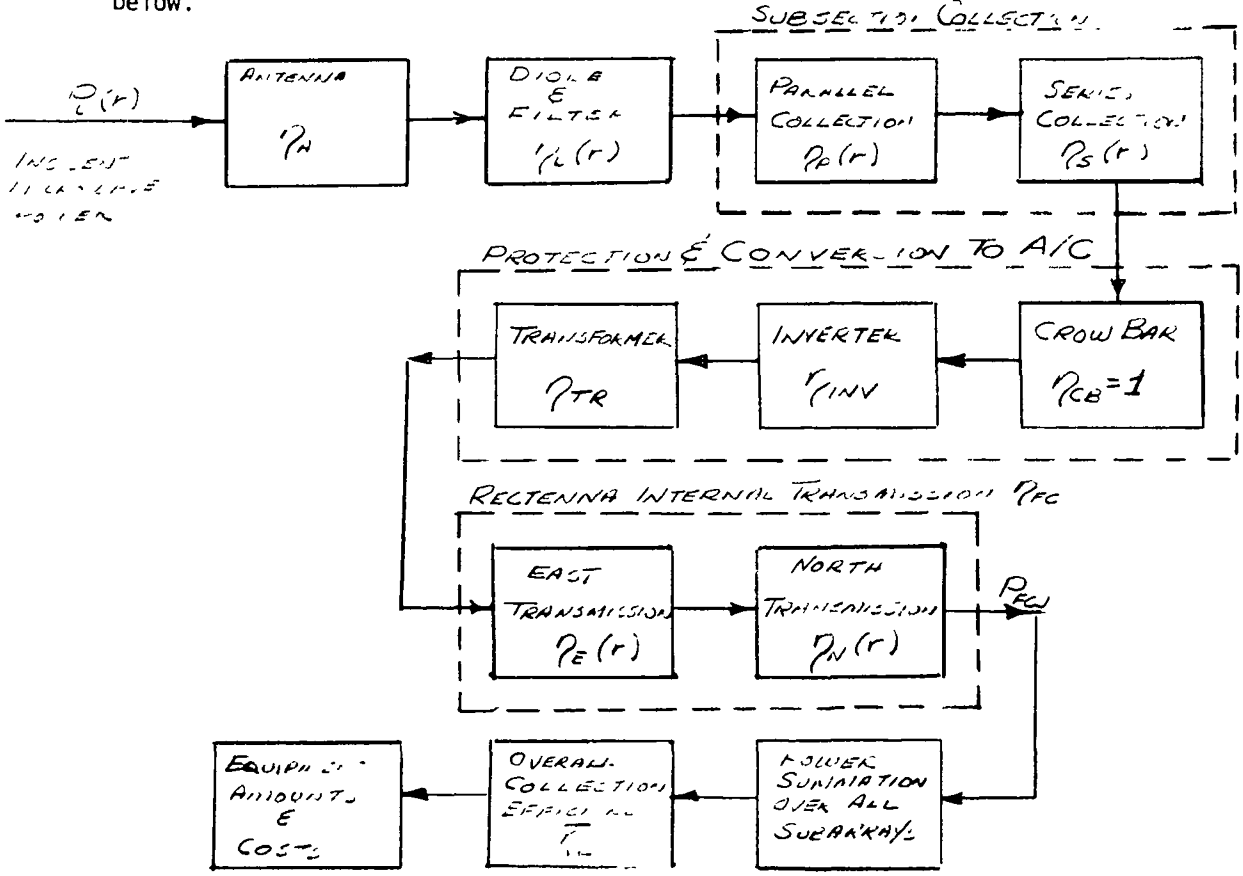
RECTENNA, POWER COLLECTION REQUIREMENTS

INTRODUCTION

The collection of microwave energy and conversion to electrical power and the conditioning of this electrical power to a form suitable for connection into an electrical power distribution system is addressed in this appendix. This power collection system has much in common with the conversion of sunlight to electrical power by solar cells and the conditioning of power for transmission to the microwave antenna system. Both systems involve combining a very large number of low voltage, lower power sources to provide a single or at best, a few high voltage, high power outputs. They differ in that the solar cells have nearly uniform characteristics, while the microwave conversion involves combining conversion devices with continuously varying input characteristics. The solar cell collection system is optimized for weight associated with interconnecting conductors, while the rectenna land area and structural requirements may be more dominant than the mass of conductors.

Rectenna Systems Flow

The rectenna systems flow and efficiency is described in the figure below.



As the distance from the center of the array increases, the efficiency of the chain decreases, while the equipment to collect this power increases. At some distance the collection of power is no longer economically feasible. To establish this cutoff point, some cost per Kw will have to be established for the rectenna, together with the cost increase per Kw output for the balance of the SPS system.

Microwave Beam Considerations

The intensity of microwave radiation in the plane at right angles to the direction of propagation of the microwave beam is given by:

$$\rho(r) = \rho(o)e^{-kr^2}$$

$\rho(o)$ is the intensity in Mw/Cm^2 at the center of the beam

r is the distance from the center of the beam in kilometers

k is a proportionality constant in kilometers^{-2}, depending upon the taper from center to edge of the beam

$\rho(r)$ is the intensity at distance r from the center of the beam

The integration overall area of the rectenna gives the power collected:

$$P = \frac{\pi \rho o}{k} (1-e^{-kR^2})$$

Where R is the radius of the microwave beam at the outside edge of the rectenna.

P = Power collected in Mw

The voltage output and power conversion efficiency from individual diode varies with the incident intensity. Equal blocks of power from various segments of the antenna at fixed currents and voltages will be collected. An example of collection and power management of low voltage sources are designs based on solar cells in space. Skylab I. was the largest solar array flown to date, and its arrays provided from 6 to 10 Kw. It would appear reasonable that larger amounts of power could be handled by a rectenna on the ground, and for initial studies, 500 Kw per panel, with an output of 1000 V DC might be a reasonable set of input data. For a 5 Gw rectenna, this would result in about 10^4 power blocks. Each power block would, on the average, occupy 0.1 percent of the total recetnna area.

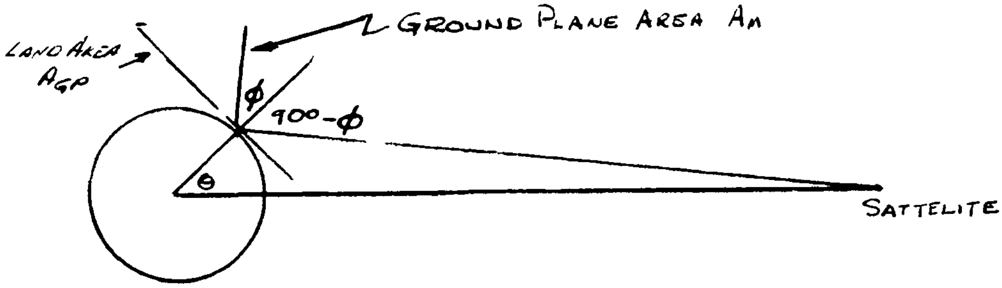
Land Area Considerations

Since the microwave receivers are mounted above a ground plane which is normal to the incident beam each power block will be mounted on columns so

as to be normal to the beam and not interfere with its adjacent neighbors. Four angles determine the orientation of the ground plane, the land area requirements and the structural support requirements.

The first angle is determined by the latitude of the rectenna installation, assuming that the satellite is in an equatorial plane, as seen in Figure IV-APP-1. The area of a flat horizontal plane required to intercept the incoming microwave beam is:

$$\frac{Am}{\cos \phi} = Agp$$



θ = Latitude

FIGURE IV-APP-1

Where: Am = The area of the microwave beam at right angles to the direction of travel

θ = Latitude

$\phi = 90° - \theta - \tan^{-1}\left(\frac{\sin\theta}{r/r_e - \cos\theta}\right)$

Aga = Ground area

The second angle is established as follows: In the north, south direction, the land area in any practical case will not be absolutely horizontal, so that the radius in the north, south direction is increased or decreased depending on its angle with respect to the horizontal, as shown in Figure IV-APP-2.

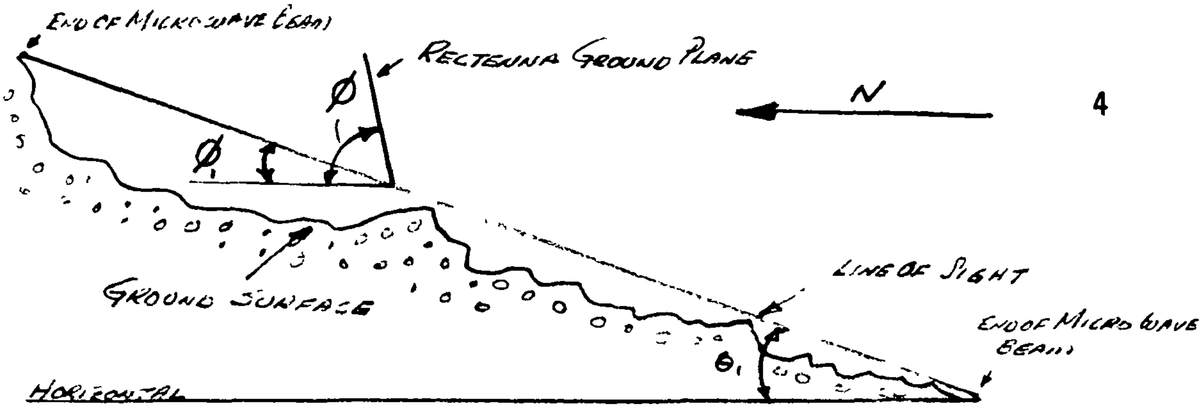


FIGURE IV-APP-2

The ground area requirement then becomes:

$$Aga_1 = \frac{Am}{\text{Cos } (\phi \pm \phi_1)}$$

Where θ_1 = Angle of line between end points of beam in N-S direction and the horizontal

A similar treatment must be made in the east-west direction, resulting in the third angle ψ_1.

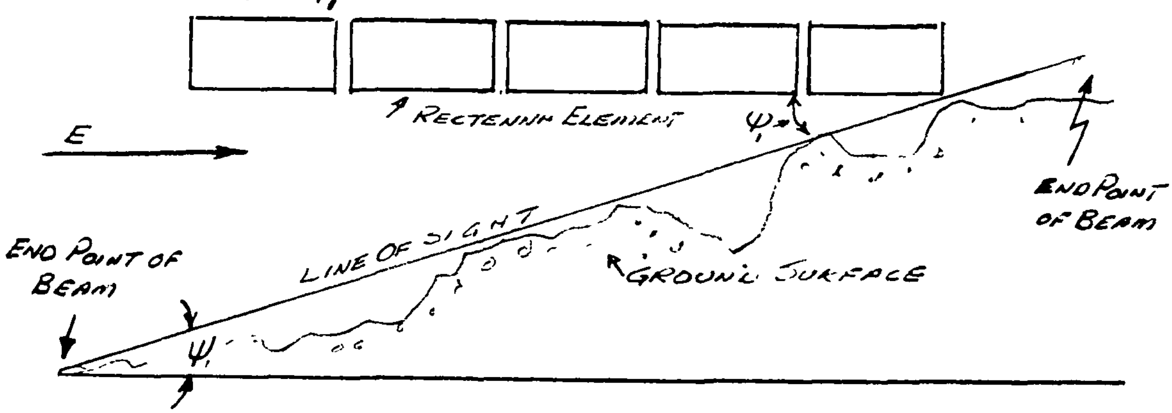
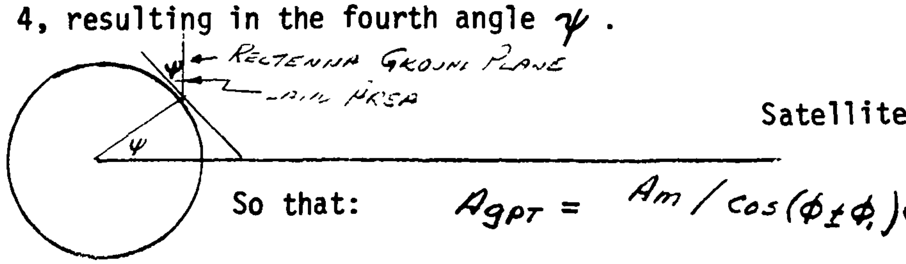


FIGURE IV-App-3

$$\text{Then } Aga_2 = \frac{Aga_1}{\text{Cos } \psi} = \frac{Am}{\text{Cos } (\phi \pm \phi_1) \text{ Cos } \psi_1}$$

The satellite may not be located directly over the meridian as shown in fig. 4, resulting in the fourth angle ψ.



So that: $A_{gPT} = Am / \cos(\phi \pm \phi_1) \cos(\psi \pm \psi_1)$

FIGURE IV-APP-4

The satellite may not remain directly over same point on the ground, and this motion will result in some power transmission loss depending upon the angles with respect to center of the rectenna.

Finally, the amount of structural support will depend upon the end points in a rectenna row as seen in Figures IV-APP-2 and IV-APP-3.

Power Collection

The Rectenna Element: The rectenna element which is used to convert microwave energy into DC power is considered to have a cell area of 53 cm^2 at 2.45 GH_Z. The power incident on the rectenna element:

$$P(r) = \rho(r)\ Ac = 53\ \rho(r)$$

Where:

$P(r)$ = Power received by diode at distance r from the center of the incoming beam in mw

$\rho(r)$ = Incident intensity at radius r in mw/cm^2

Ac = Cell area occupied by a rectenna element in cm^2

Then:

$$P(r) = 53\ \rho(r) = 53\ \rho_{o} e^{-kr^2} = P_{(o)} e^{-kr^2}$$

The rectification of this incident power involves a number of losses, as shown in Figure IV-APP-5.

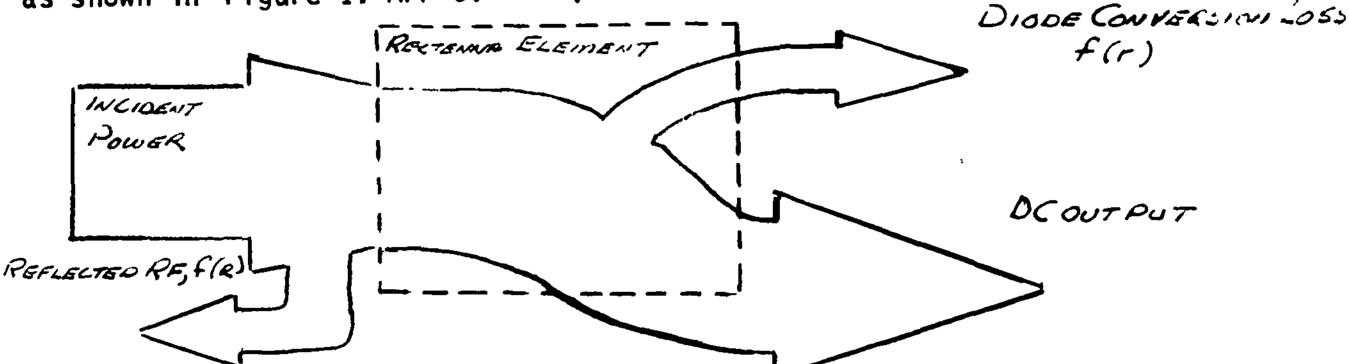


FIGURE IV-APP-5

Note that depolarization and other microwave transmission losses are considered to have already occurred and are taken care of in the incident power term. The overall conversion efficiency assumed in earlier studies is shown in Figure IV-APP-6. For purposes of preliminary studies, the conversion efficiency is reasonably described by the equation:

$$\eta_c = CP_{inc}^{\ n}$$

Where: η_c = Conversion efficiency

C = Constant

P_{inc} = Incident microwave power mw

n = Constant

The constants C and n are easily obtained from log-log plot of P_c vs. P_{inc}

Then:

$$P_c = \eta_c\ P_{inc}$$

$$P_c = C\ P_{inc}$$

$$P_{inc} = P_o e^{-kr^2}$$

$$P_c = CP_o^{n+1}\,{}_c^{-k(n+1)r^2} = P_{co}e^{-\theta r^2}$$

The last expression is exactly the same form as the expression for the incident beam; hence, conversion losses appear as an increase in the incident beam taper.

Subarray Power Collection Considerations

The output of a rectenna element as a function of its position in the rectenna has been described. This power is now collected in parallel and series in a subarray unit a given amount of the power at a given DC level is achieved. The voltage and current outputs from a rectenna element are determined as follows:

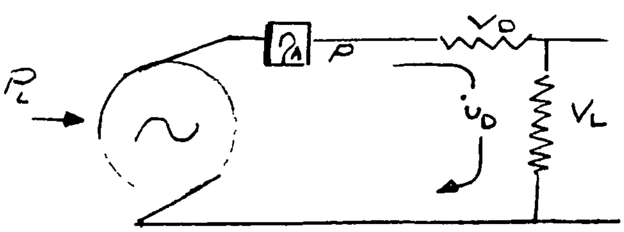


FIGURE IV-APP-6

Let the forward voltage drop of the diode be a constant V_D . Then:

$$P_c = i_D V_L = \eta_A \eta_D P_c$$
$$P_c \eta_A = i_D (V_D + V_L)$$
$$i_D = P_c \eta_A \eta_D / V_L$$
$$P_c \eta_A = P_c \eta_A \eta_D (V_D + V_L)/V_L$$
$$1 = \eta_D (V_D + V_L)/V_L$$
$$V_L = \eta_D V_D / (1-\eta_D)$$
$$i_D = P_c \eta_A (1-\eta_D)/V_D$$

Having established the current and voltage from each rectenna element, the next question to be considered is how to collect in series and parallel. Connecting the current from a number of rectenna elements in parallel is shown in figure IV-APP-7.

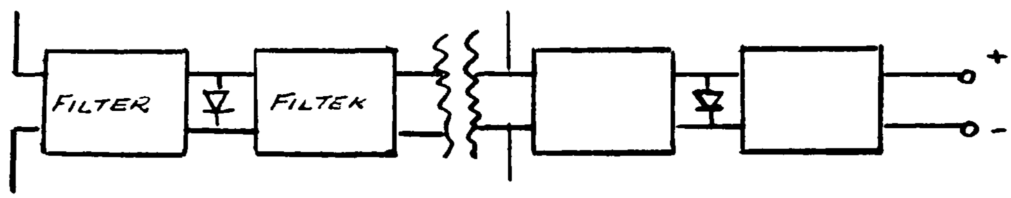
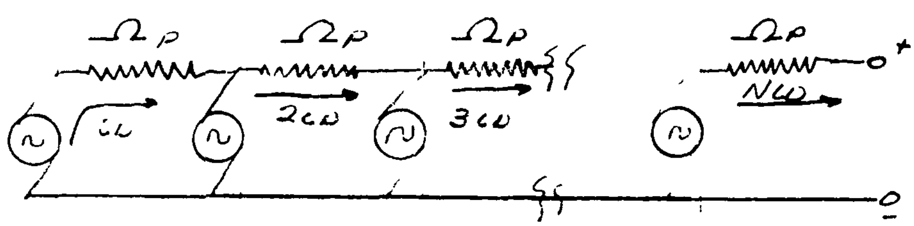


FIGURE IV-APP-7

The equivalent DC circuit is shown in figure IV-APP-8



V_L I_{PS}

$$I_{PS} = N i_D$$
$$= P_c \eta_A (1-\eta_D)/\eta_D V_D$$

The output current should be set at a value sufficiently high to burn clear a shorted diode. It is assumed that η_a is a constant and that η_D can be obtained from values previously published for Shottsky diodes by

Ratheon. The I^2R losses experienced in collecting in parallel are:

$$P_{LPD} = i_D^2 \Omega_{PS} + 4 i_D^2 \Omega_{PS} + 9 i_D^2 \Omega_{PS} \cdots N^2 i_D^2 \Omega_{PS}$$

Where: P_{LPD} is the power lost in the string of diodes paralled to produce I_p Ω_p is the resistance of one rectenna element filter section.

$$P_{LPD} = i_D^2 \Omega_{PS} \sum_{J=1}^{N} J^2$$

BUT FROM THE DEFINITION OF THE GEOMETRIC SERIES

$$\sum_{J=1}^{N} J^2 = \frac{J^N - 1}{J-1} = \frac{N^N - 1}{N-1}$$

$$P_{LPD} = \left[P_c^2 \eta_a^2 (1-\eta_D)^2 / V_D^2 \eta_D^2\right] \Omega_{PS} (N^N - 1)/(N-1)$$

$$\eta_{SP} = \frac{\left[N P_c \eta_a \eta_D - \left[P_c^2 \eta_a^2 (1-\eta_c)^2 / V_D^2 \eta_D^2\right] \Omega_{PS} (N^N - 1)/(N-1)\right]}{N P_c \eta_a \eta_D}$$

$$= 1 - \left(P_c \eta_a (1-\eta_D)^2 / V_c^2 \eta_D^2\right) \Omega_{PS} (N^N - 1)/N(N-1)$$

Where η_{sp} is the efficiency factor for collection of the subarray parallel elements. Note that there is no additional wire used to collect in parallel, and that the length of this parallel string is $N\sqrt{A_c} = 7.5 N$ cm.

The next step is to collect in series up to the output voltage of the sub-section.

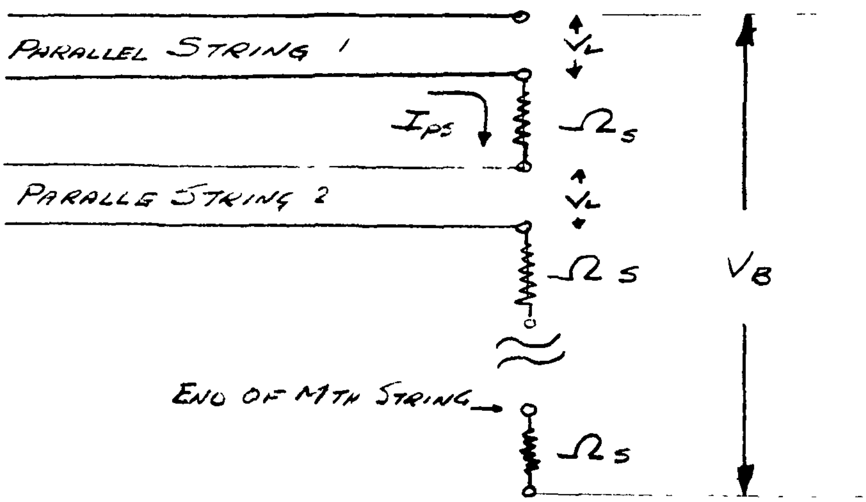


Figure IV-APP-8

From figure IV-A_P-8

$$V_B = M(V_L - I_{PS}\Omega_S)$$

$$M = V_B/(V_L - I_{PS}\Omega_S)$$

WHERE: V_B = THE OUT PUT VOLTAGE OF THE SUBARRAY

Ω_S = THE RESISTANCE OF A UNIT CONNECTION BETWEEN PARALLEL STRINGS.

To minimize the overall I^2R loss due to connecting in series the value of V_b should be made as high as possible. However, high voltage across the standoff of the diodes and the ground plane is small, a breakdown to ground could occur, which will limit the value of V_b. The question of Corona discharge and leakage due to dust and moisture require further study.

The I^2R loss due to series connections as found as follows:

$$P_{LSO} = I_{PS}^2 M \Omega_S$$

$$\eta_{SS} = (I_{PS} V_B - I_{PS}^2 M \Omega_S)/I_B V_B$$
$$= 1 - \frac{I_{PS}}{V_B} M \Omega_S$$

and the overall collection efficiency for a subarray becomes:

$$\eta_{CT} = \eta_{SS} \eta_{SP}$$
$$= (1 - P_c \eta_A (1-\eta_D)^2 / V_D^2 \eta_D^3) \Omega_P (N^N - 1)/N(N-1))\times$$
$$(1 - N P_c \eta_A (1-\eta_D)/\eta_D V_D V_B) M \Omega_S)$$

It should be noted that $M \Omega_S$ represents additional wire for connections within the array. The area of the rectenna required to collect this power is NMA_C or A_{SA}.

Protective devices (crow bars) will be required at the output from a subarray to protect from a load interruption which would produce high voltage breakdown of the diodes.

Transmission from Subarray to Collection Point Considerations

The output from the subarray is limited in the voltage which can be developed by the geometry of the rectenna element; however, high voltage should be used to minimize transmission losses from the subarray to the central collection point. At this point, the interaction of connecting many subarrays in parallel is not defined. It is assumed that inversion is performed on the output of each subarray and that the inverters can be paralleled. The output AC voltage should be made as high as possible. The exact design of the transmission line is considered beyond the scope of this initial study, but will markedly affect the cost of rectenna construction.

The power delivered to the inverter is:

$$P_D = P_i \eta_a \eta_0 \eta_{CT}$$

The inverter efficiency is a constant η_{ac}

Pac (The power to be delivered to the central collection point) = $P_D \eta_{ac}$

The final power collected is:

$$P_{FC} = P_D \eta_{AC} - I_{AC}^2 R_T$$

It is assumed that power is first laterally transmitted to the Y axis and then to the center of the rectenna along the X axis.

The details of the transmission line not having been completely worked out the impedance and losses due to power factor will be ignored.

The value of R_t has two components:

R_{nj} - The resistance in the east, west direction of the transmission line from the Jth subarray in the center line of the rectenna.

R_{mj} - The resistance in the north , south direction from the center line above to the center of the rectenna.

The subarrays are arranged along the ground plane of the rectenna. The N dimension in the east, west direction and the M dimension in the north, south direction. The M dimension is limited in any rectenna row by H, the length of the ground plane. A typical arrangement is shown in Figure IV-APP-9.

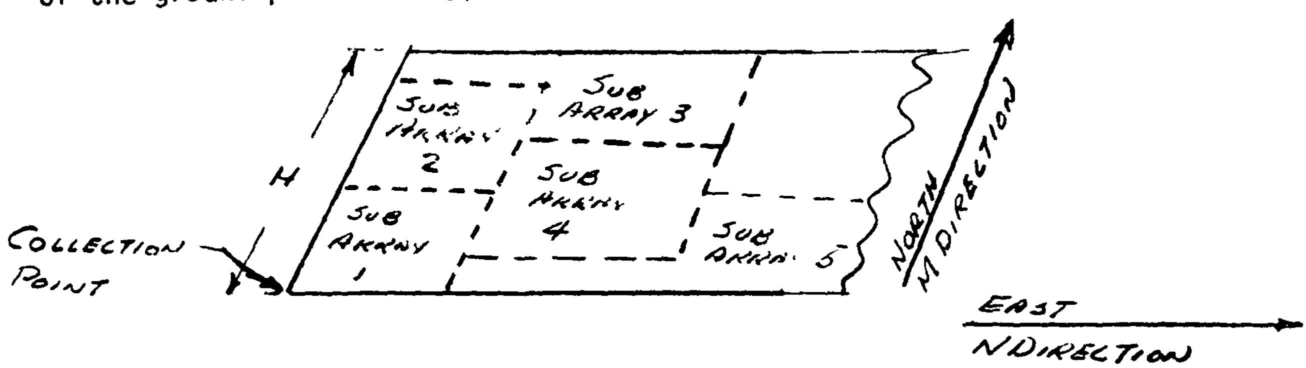


FIGURE IV-APP-9

Then the length of R_{ej} on a section of several subarrays is:

$$\sqrt{A_c}\sum_{J=1}^{J-1} N_J$$

Where: N_J is the number of rectenna elements in the Jth array and since the power take-off is in the lower left corner of the array, the length is determined by the collection subarrays which have preceded it.

Since the rectenna must be split up into finite areas to take care of terrain, the length of the transmission line leaving the segmented portion of the rectenna will not necessarily lie in the horizontal plane so that the length of R_{ej} has two components, one on the array and one over the terrain and the length on the section of several subarrays described above.

The total length of $R_{EJ} = L_A \sum_{P=1}^{P-1} N_P / \cos\varphi_2 + \sqrt{A_c}\sum_{J=1}^{J-1} N_J$

With the constraint that $\sqrt{A_c}\sum_{J=1}^{J-1} N_J \leq L_A$

Where: L_A = length of a Rectenna Section

N_P = Number of Subsections

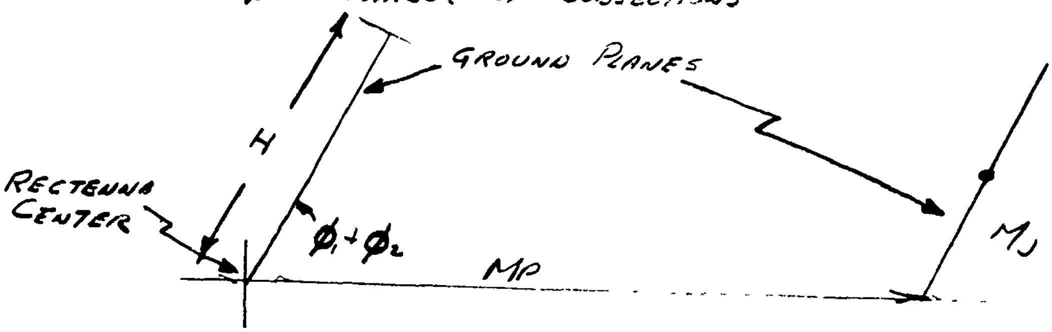


FIGURE IV-APP-10

In the north, south direction there are two dimensions to be considered; the position on the ground plane and the location of the ground plane with respect to the rectenna center line as shown in figure 11.

The length of $R_{M_J} = H \sum_{P=1}^{P-1} M_P / \cos(\phi_1 + \phi_2) + \sqrt{A_C} \sum_{J=1}^{J-1} M_J$

Subject to the constraint that the value of the second term is always less than H.

Assuming some value of resistance per unit length of transmission line Ω_T, the resistance of the transmission line from the J^{th} subarray in the P^{th} section is:

$$R_{T_{PJ}} = \Omega_T \left(H \sum_{P=1}^{P-1} M_P / \cos(\phi_1 + \phi_2) + \sqrt{A_C} \sum_{J=1}^{J-1} M_J + L_A \right.$$

Next to find the efficiency of transmission the power delivered neglecting impedance effects

$P_{FC} =$ [illegible] $- I$ [illegible]

[illegible] $I_{H} R_T / V_A$ [illegible]

Computer Program Outputs

Along each row determine:

(1) Total length of series connections vs. X direction in row.

(2) Total number crow bars, inverters and step-up transformers vs. X radius

(3) Total length of east,west transmission wire vs. X distance from center.

(4) Total length of north,south transmission wire vs. Y distance from center line.

(5) Total power vs. X at various Y.

Input: 1. Unit costs for wire/unit length

2. Weight of wire/unit length

3. Unit costs for crow bar, inverter and transformer

4. Weight breakdown on items in 3 above

5. Cost per KW for balance of SSPS

Output: 1. Total dollar cost vs. power along X direction in each row (i.e. %$ vs. % power??)

2. Masses of material vs. power along X for each Y.

Next a subroutine should be developed to determine the items described in the next section. In Figure IV-APP-11 is shown the accumulated dollar cost of capital equipment vs. the accumulated power output for various rows of the rectenna. The curves are arbitrary except that the general shape is correct. The slope of this curve Δcost/Δpower is determined at each step and the calculation is terminated when Δ cost/Δ power $\geq$ C

At this point determine P_c/P_t for the row which is η_c limiting collection efficiency due to cost.

This process if repeated for each row. Then:

$$\sum_{\text{all Rows}} P_c / \sum_{\text{all Rows}} P_D = \bar{\eta}_c$$

The average collection efficiency

$$P \text{ available} = P_t \bar{\eta}_c$$

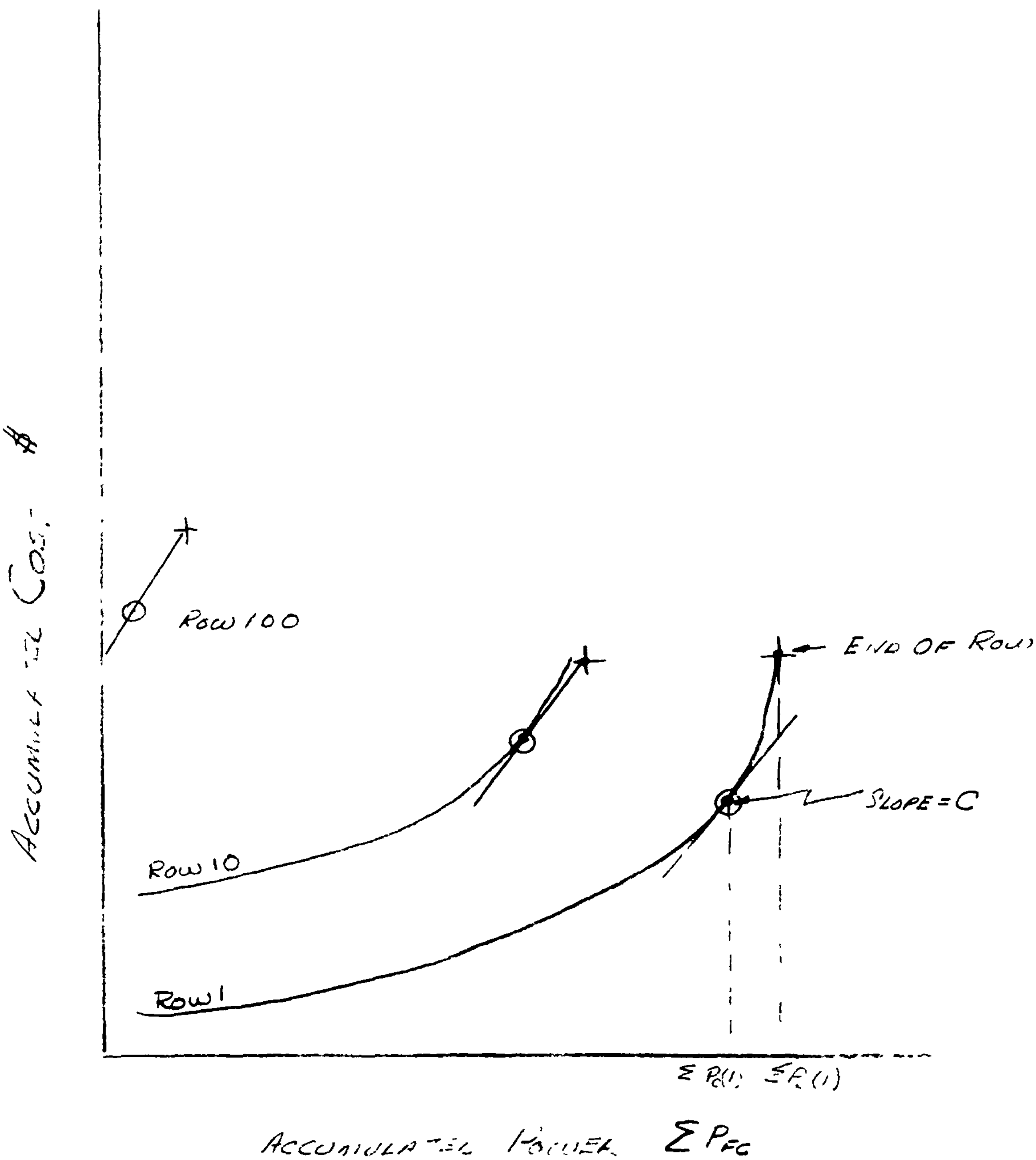


FIGURE IV-APP-11

Distribution is 50 percent of capital cost of utilities.

Future Work

Collection for rectenna is an inverse distribution operation. Reliability must be established. The computer program described in the preceding section provides individual wires, but in practice, the transmission line might be tapered, as more subarrays are added to the line. The mass of conductor should be about the same for either case. There is a question of whether alternate paths to the central collection point should be provided. In the event that a line fault should develop between the subarray and the central collection point, some provision must be made to isolate that section of line without interrupting the supply from that subarray. Any system which provides alternate paths between the subarray and the cetnral collection point will require more wiring, hence have a higher cost.

The cost of this collection system, based upon extrapolation of Electrical Transmission and Distribution Reference Book by Central Station Engineers of the Westinghouse Electric Corporation, copyright 1950, East Pittsburgh, Pa., (figure 4, page 695), is about $100 per KVA in 1950 dollars, or around $300/KVA and may be as high as $500/KVA in 1985 dollars. Note also that is voltage control is required in the solar collection system, so that the structure is not used for collection, a similar cost will be incurred in that system, but should be lower since the power output density is lower.

Voltage drop limits need to be established; "The Standard Handbook for Electrical Engineers." Permissible Voltage Drop, Section 16-88 states:

> "Permissible drop in voltage between the supply and substation and first transformer should not exceed 10 percent on transmission lines."

The scheme described in this report involves the paralleling of 10^4 subarrays, which on the average contain around 10^5 diodes. The AC output from these subarrays must be in parallel if they are to be combined for transmission. The control system for controlling relationships and paraleling control has not been considered in this preliminary look at collection, but is the equivalent of paralleling 10^4 generators. Collection and isolation at some intermediate power level around 50,000 Kw will probably be required. Here again, the question of the amount of interconnect redundancy vs. reliability requires further study along with operating voltage.

Grounding Considerations

There are a number of grounding requirements inposed by the rectenna.

a. The ground plane reflectors from each subatation of the rectenna must be adequately grounded during normal operation.

b. The crow bar from each subarray must dissipate 500 Kw whenever the load is interrupted and during startup of the rectenna; 104 such sources will be operating if there exists a complete load interruption.

c. Lightning grounds will be required for the ground plane and overhead transmission lines.

d. Transfer neutrals must be grounded.

e. Fences and other equipment in the vicinity of high voltage are normally grounded.

The exact type of ground system will depend upon the electrical characteristics of the earth in the region it is installed. In moist ground, iron pipes may be sufficient, while in desert or rocky areas, a grid work buried in the ground may be required. Specifications for power to be dissipated and allowable voltage drops and the changes in ground conductivity under protracted dumping of the output while the load is interrupted need further study.

Microwave Reception

Changes in the intensity of the incident microwave beam due to failures or errors in the antenna system atmospheric effects, together with equipment failures and load changes on the ground will produce transients in the rectenna collection system. This may show two types of effects, surges in peak voltages and frequency which are harmonics of the collection systems. Line protection and possible interference with microwave reception can result and need investigation. Corona discharge from overhead lines may also affect microwave reception and hence, needs further investigation.

Alignment Considerations

The periodic motion of the earth due to tidal action, and long term changes in the earth's surface will produce misalignments of the rectenna ground plane arrays with the incoming microwave beam. Temperature variations from day-to-night can be expected to produce similar effects. These effects can be expected to produce changes in reception efficiency. Provisions for periodic alignment of the rectenna subarrays and designs which take into account temperature changes are required to maximize rectenna conversion efficiency.

Summary and Conclusion

An outline of the calculations required to make a first approximation of the mass and cost of a rectenna collection system have been made. The effects on rectenna efficiency have been described and an approach to a cost

trade-off between rectenna materials and efficiency has been outlined. The computer program will provide additional refinement to the estimate of rectenna efficiency and some initial cost comparisons.

The results of this initial modeling shows that there are a number of safety features and reliability considerationswhich will require incorporation into the rectenna design.

Recommendations

(1) It is recommended that detailed programming of the rectenna collection system be carried out as quickly as possible; some preliminary estimates are possible using hand calculations. The effects of the rectenna efficiency changes on the cost and performance of the balance of the SPS system need to be investigated parametrically for rectenna optimization studies.

(2) The operating voltages, paralleling controls, redundancy isolation requirements, grounding requirements, and structural alignment need performance specifications and it is recommended that an RFP be issued to study these area when funds become available.

V. SPACE CONSTRUCTION AND MAINTENANCE SYSTEM

A. SYSTEM DEFINITION STUDY CONSTRUCTION RESULTS

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The Boeing SPS Systems Study, Part I, included an analysis of the construction requirements and construction concepts for three SPS configurations - a thermal engine and photovoltaics at concentration ratios of 1 and 2 (CR1 and CR2). Requirements for construction at LEO and GEO were analyzed and compared for each configuration. Since the objectives of Part I of the study concerned power conversion alternative evaluation and the development of data related to space construction location, this initial construction analysis was not directed toward developing absolute mass and cost numbers, but was oriented toward construction differences in satellite types and construction sites. Toward this end, the construction analysis developed the following data for each alternative energy conversion concept and construction location:

- definition of construction concepts
- definition of type of facility to be used
- definition of construction sequences
- definition of time allocations for each major construction task
- definition of functional requirements for the construction machinery
- definition of requirements for the number of each type of construction machine and their operating rates
- number of construction personnel required

For simplification, the assumption was made that each satellite would be constructed in one year, machines were given a fixed operating rate, and the number of machines varied to meet the overall one year limit. Antenna construction was not analyzed since antennas were common to all alternatives, but time was allocated for attaching antennas to the array structure, and estimates were made for antenna construction crew size.

As the various satellite types were analyzed, a set of underlying principles (objectives, goals, guidelines) evolved that were incorporated into all of the various construction concepts. The philosophy which evolved from the assembly of these principles could not always be satisfied, but they do represent an initial set of criteria for space construction which has some engineering or operational basis for existence. This "construction philosophy" is summarized in the following:

CONCEPT		RATIONALE
Facilitized Construction	-	Do not have to build in extra strength (mass) into every satellite in order to support construction equipment.
	-	Construction operations can be decoupled.
Decoupled Operations	-	Construction operations should be independent as possible so that a slow down or stoppage in one operation has minimum impact on others.
Major Subassemblies in Parallel	-	Fabricate major subassemblies in parallel in separate facility locations so that maximum time can be allotted to each subassembly fabrication.
Work From One Side	-	Simplifies machine resupply logistics.
	-	Simplifies personnel access.
	-	Simplifies facility.
	-	Simplifies removing completed satellite from facility.
Continuous Beams	-	Continuous beams, whether curved or straight, minimize the number of joints, and eliminates the need for some joint plug assemblies.
Construction Machine Tracks	-	Using tracks for construction machine is preferred to the use of "overhead crane" technique for getting the machines to the desired location: • machine located closer to work (long booms not required) • provides surface to attach temporary beam supports • allows independent activity of multiple number of machines (not constrained by number of overhead cranes)
Moving Beam Machines	-	Placing beam machines on tracks such that the machine backs away from "extruded" beam is preferred over fixed beam machines: • continuous longitudinal beams can be made (no longitudinal butt joints required) • cross frames can be started as soon as longitudinal beam machines pass the joint area

CONCEPT		RATIONALE
Support the Beams	-	The beams must be supported as they are fabricated to eliminate undesired stress and unguided end positions.
Avoid Use of Free Flyers	-	Machines that free fly are not desired. The satellite components are too frangible to tolerate accidental collisions.

Functional requirements for types of construction equipment, quantity and operating rate were defined and estimates made of the number of direct construction and supporting personnel (see figures V-A-1 and V-A-2). Figure V-A-3 compares sizes of facilities.

In the Part I study, a preliminary constructability rating was derived for the six combinations of configuration and construction location. Figure V-A-4 graphically represents the relative values of this rating technique. The parameters used in the rating were given weighting factors to reflect their importance. For instance, assembly complexity was judged to be of the greatest importance. The photovoltaic, CR1, satellite is about 50 percent better from the constructability aspect than the thermal engine satellite. The photovoltaic CR2 satellite falls in between the other two in constructability rating.

The truss configuration satellites were conceived as a way to simplify construction. Boeing has applied a similar approach to the thermal engine reflector support structure by changing from a parabolic support for the reflector facets to a cylindrical support. This improved construction operations, but increased the facet area requirement by four percent. Eliminating the reflectors in changing the photovoltaic to a CR1 improved the constructability by placing the solar cell blankets on a flat side of the truss structure.

The rating technique indicates very little difference between the LEO and GEO construction location; therefore, constructability is not considered a strong discriminator in that trade.

Collisions with objects in LEO is a concern during construction. Approximately thirty collisions are predicted during LEO construction and transit to GEO. For thirty years operation in GEO about 10 collisions are predicted. The probability of significant damage from a collision is considered to be very low.

Of greater influence on the LEO/GEO decision is the requirement for berthing the large sections after transport from LEO. A concept for accomplishing the berthing is illustrated in figure V-A-5.

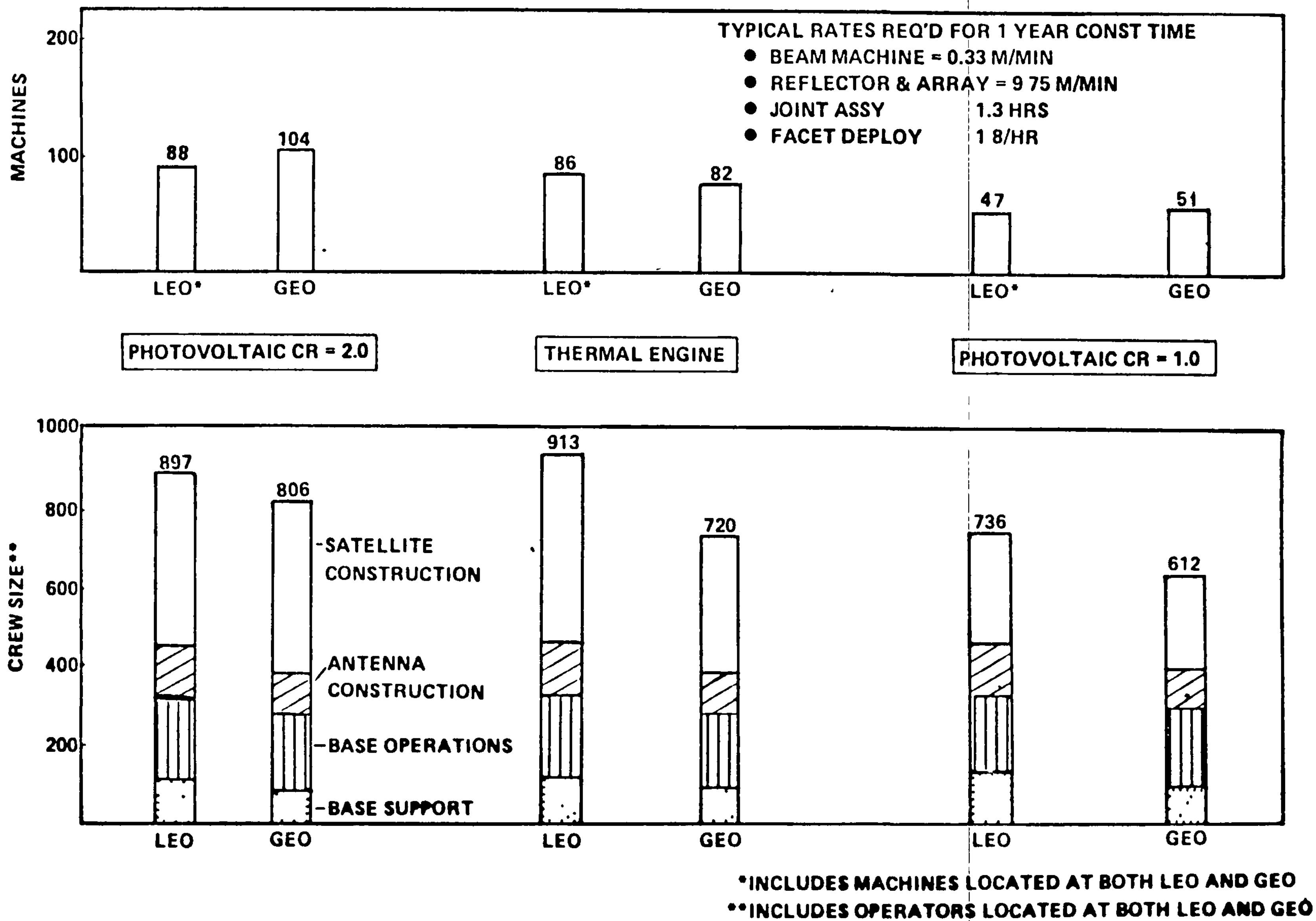


FIGURE V-A-1 - CONSTRUCTION MACHINE AND CREW SIZE COMPARISON

	CR - 2.0 Photovoltaic satellite				Thermal engine satellite				CR = 1 0 Photovoltaic satellite			
	LEO construction		GEO construction		LEO construction		GEO construction		LEO construction		GEO construction	
	LEO base	GEO base	LEO base	GEO base	LEO base	GEO base	LEO base	GEO base	LEO base	GEO base	LEO base	GEO base
Base management	(10)	(5)	(5)	(10)	(10)	(5)	(5)	(10)	(10)	(5)	(5)	(10)
Satellite construction	(302)	(135)	(0)	(414)	(337)	(119)		(331)	(186)	(95)	—	(220)
Management	72	22	—	80	21	14	—	21	46	22	—	42
Machine operators	152	32	—	170	146	20	—	140	78	20	—	57
Subsystems	12	15	—	24	30	30	—	30	12	15	—	24
Maintenance	23	28	—	56	68	30	—	68	28	16	—	43
Test and checkout	38	38	—	78	72	25	—	72	22	22	—	54
Antenna construction	(84)	(54)	—	(84)	(84)	(54)	—	(84)	(84)	(54)	—	(84)
Base operations	(138)	(68)	(82)	(124)	(138)	(68)	(82)	(124)	(138)	(68)	(82)	(124)
Management	12	8	8	12	12	8	8	12	12	8	8	12
Data processing	6	4	4	6	6	4	4	6	6	4	4	6
Base maintenance	42	19	19	42	42	19	19	42	42	19	19	42
Transportation	24	10	24	10	24	10	24	10	24	10	24	10
Materials handling	46	19	19	46	46	19	19	46	46	19	19	46
Communications	8	8	8	8	8	8	8	8	8	8	8	8
Base support	(64)	(37)	(23)	(64)	(64)	(37)	(23)	(64)	(64)	(37)	23)	(64)
Management	7	5	5	7	7	5	5	7	7	5	5	7
Utilities	14	8	2	14	14	8	2	14	14	8	2	14
Hotel/food service	24	12	4	24	24	12	4	24	24	12	4	24
Medical/dental	13	6	6	13	13	6	6	13	13	6	6	13
Safety	2	2	2	2	2	2	2	2	2	2	2	2
Chaplain	2	2	2	2	2	2	2	2	2	2	2	2
control	2	2	2	2	2	2	2	2	2	2	2	2
Totals	598	299	110	692	633	283	110	613	477	259	110	502
Total	897		806		916		720		736		612	

FIGURE V-A-2 - CONSTRUCTION CREW SIZE COMPARISON

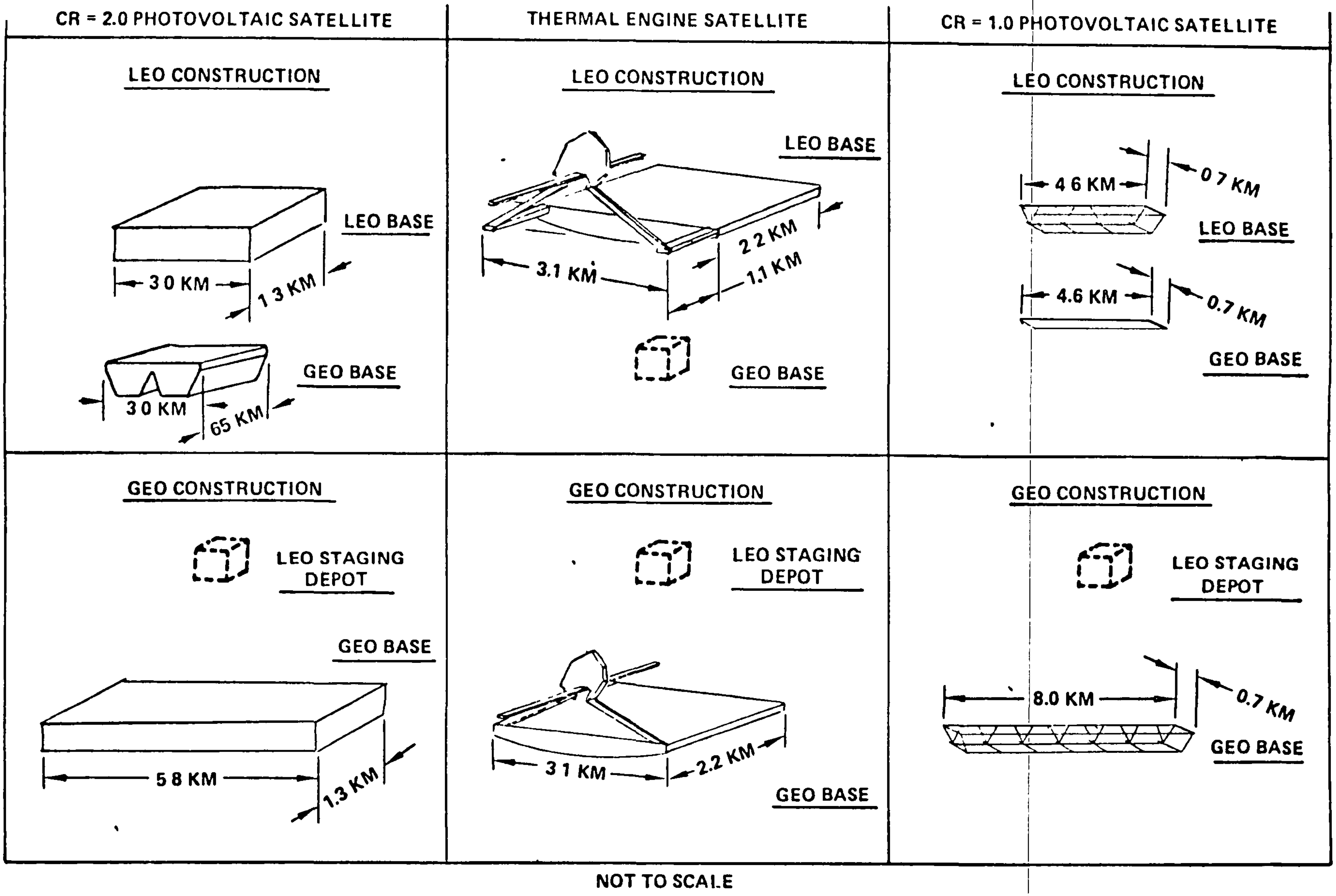


FIGURE V-A-3 - SATELLITE CONSTRUCTION FACILITY COMPARISON

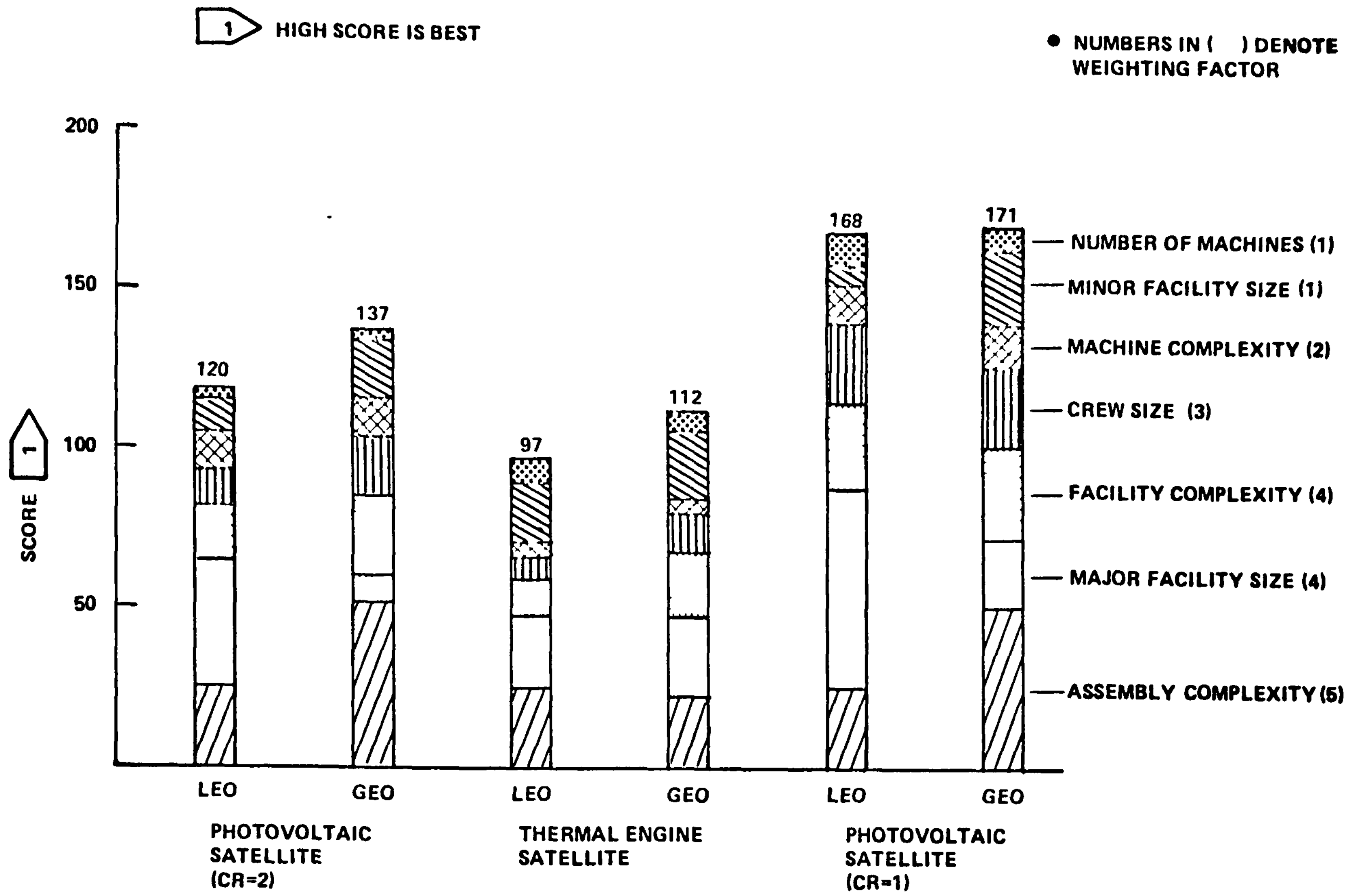


FIGURE V-A-4 - PRELIMINARY RELATIVE CONSTRUCTABILITY RATING

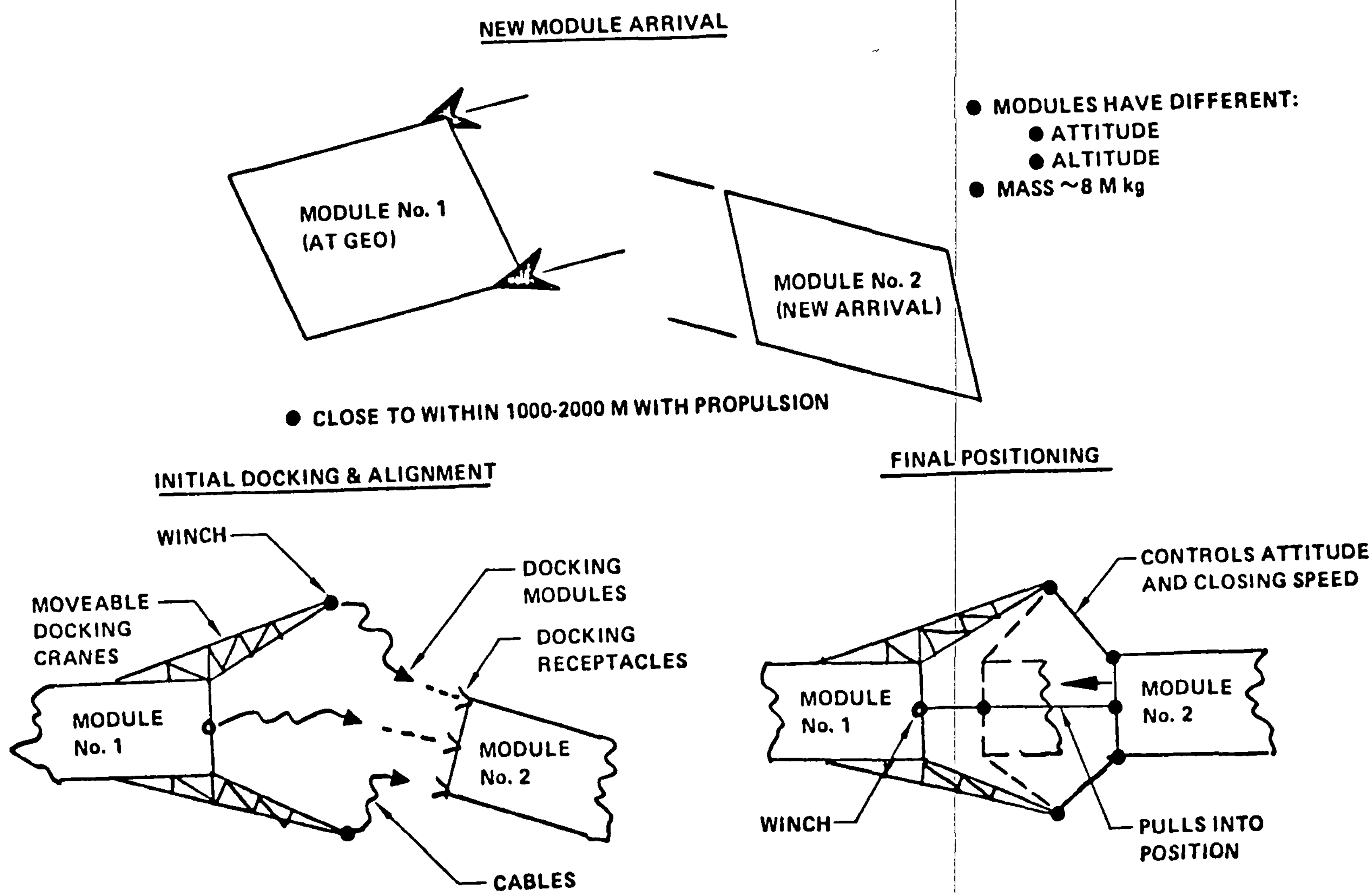


FIGURE V-A-5 - CONCEPT FOR DOCKING/BERTHING LARGE MODULES

Other conclusions from the construction analysis are that one year for construction appears reasonable in terms of machine operating rates, number of machines and crew size.

V. SPACE CONSTRUCTION AND MAINTENANCE SYSTEMS

B. ORBITAL CONSTRUCTION SUPPORT EQUIPMENT (OCSE) STUDY

S. H. Nassiff
Spacecraft Design Division

One of the key areas identified in the "study task structure" of the JSC in-house study report (JSC-11568) for solar power systems in space was equipment required to support automated fabrication/assembly of large space structures. This equipment has been designated as orbital construction support equipment (OCSE).

To further define the OCSE required in constructing large space systems, a study contract was awarded to the Martin Marietta Corporation - Denver Division under NASA Contract NAS 9-15120. The contract span was for nine months (October 1, 1976 through June 30, 1977). The objective of the study was to produce a conceptual design and system definition of the OCSE required for orbital construction of large space systems, typified by various configurations of solar power satellite systems, and to derive supporting OCSE development and cost data.

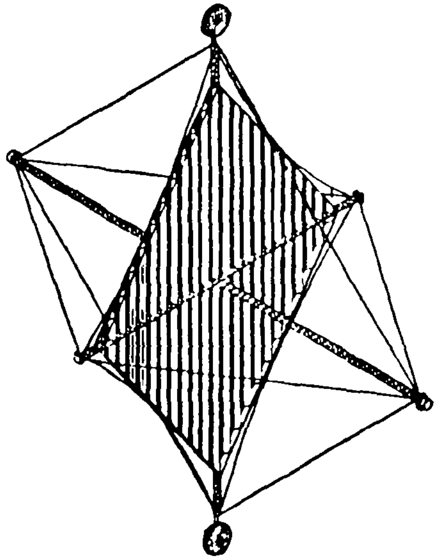
The primary emphasis for this study was directed toward OCSE needed for support of construction of a large solar power satellite (SPS) having an operational location in geosynchronous orbit, although the results are applicable to the construction of any large space system. Three SPS baseline configurations were given to the contractor for this study effort. These were the JSC photovoltaic column/cable, JSC photovoltaic truss, and the Boeing thermal cycle concepts. These concepts represent a typical spectrum of present SPS configurations and are shown in figure V-B-1.

OCSE is defined as that equipment required to support automated fabrication/assembly equipment which will have to be assembled, postioned, set up, controlled, checked out, monitored, serviced, and maintained with specially trained personnel located at the space construction site. It also considers both man and machine in the construction role. The study was divided into three parts. Part I covered OCSE requirements, Part II was concept definition, and Part III included OCSE evaluation and selection.

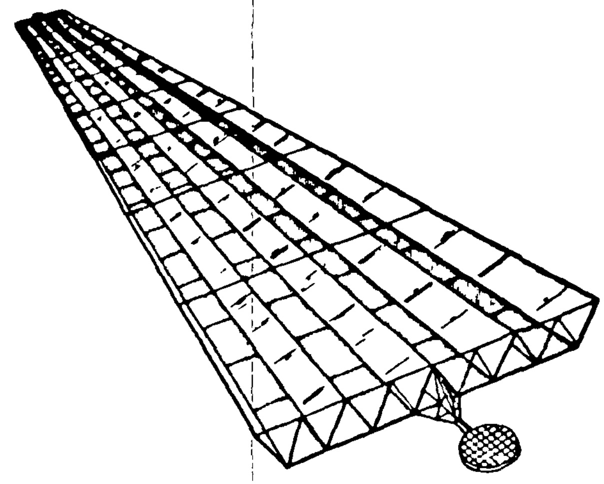
Based on the construction tasks identified in the functional analysis of the three SPS concepts investigated, requirements were identified for performing the SPS construction tasks on each SPS element. These requirements are summarized in generic processes requirements and encompasses all functions required during SPS construction/assembly. The processes were defined as follows: transport, handle, align, fasten, adjust, monitor, and checkout.

SPS BASELINE CONFIGURATIONS

Column Cable (JSC)



Truss (JSC)



Thermal (Boeing)

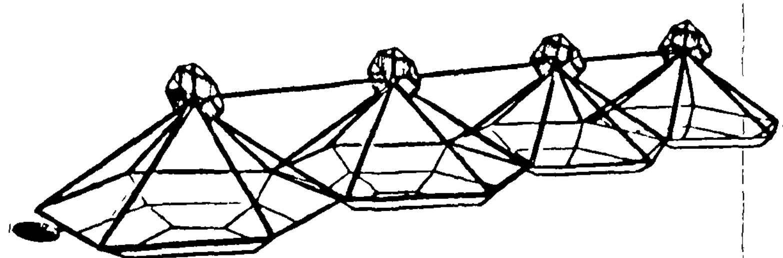


FIGURE V-B-1

Requirements were identified for each process applicable to each SPS element, for every recognized task involved in the baseline construction methods. The degree of automated vs. direct control of SPS elements, in qualitative terms, is shown as frequency of occurrence vs. unit mass in figure V-B-2. Figures V-B-3 and V-B-4 show frequency of occurrence vs. transport distance and handling distance, respectively. Although there is a high degree of scatter evident in the data, due to the diversity of elements involved in SPS construction, the data tends to suggest which group of high frequency elements might be accommodated by automated systems and the group of less frequently occurring items be more directly controlled.

An OCSE category tree was generated to ensure that an orderly approach was used in evaluating the applicability of different candidate concepts. This structured grouping, as shown in figure V-B-5, provided a quick visual reference of candidate similarities by systems characteristics such as operational utility, functional capability, and hardware utilization.

The OCSE lists generated for each SPS configuration contain items which are common to all the configurations, or to two of the three configurations. The following summarizes the types of OCSE required in the three SPS configurations:

- Transporter, Free Flying
- Transporter, Structure Attached
- Manipulator, Mobile Base
- Manipulator, Fixed Base
- Long Boom, Attached Base
- Universal Docking Device
- Aligner (EVA, TV, Laser)
- Fastener (EVA, Manipulator, Latch)
- Cherry Picker
- Universal Storage Panel
- Modular Systems (GN&C/Comm/ACS)
- EVA Hand Tools
- Monitoring, Direct Viewing
- Servicing Module
- Checkout System

Figure V-B-6 shows some of the major concept alternatives as they apply to the OCSE inventory tree established earlier.

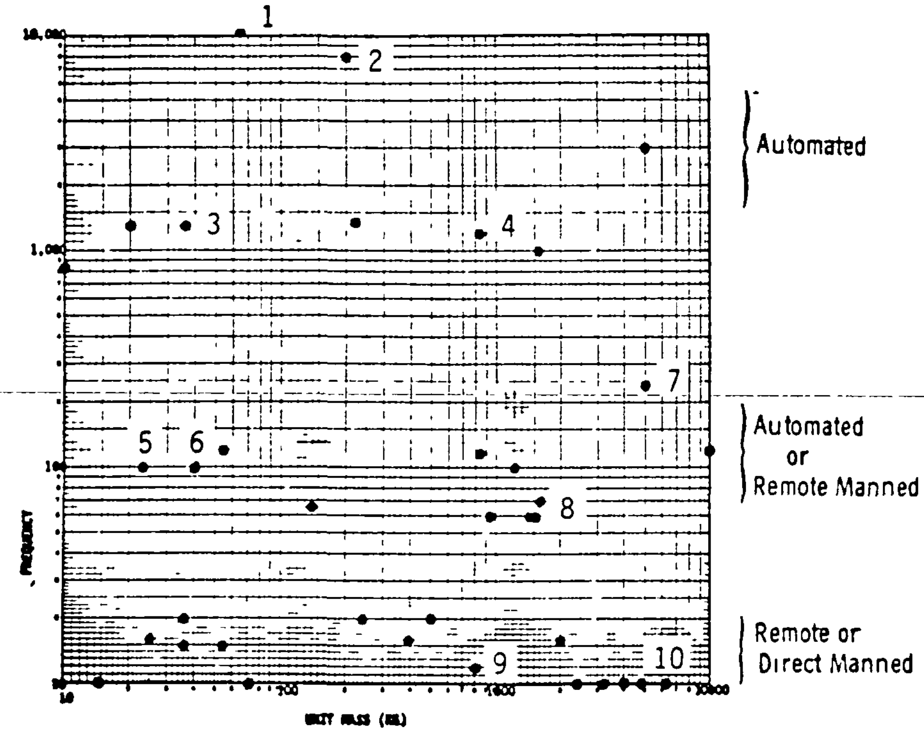


Figure V-B-2 *Element Frequency Vs Unit Mass*

<u>KEY FOR NUMBERED EXAMPLES</u>:

1 Reflector Facets (Boeing Thermal)

2 Subarrays, MPTS

3 Column Beams (Column/Cable)

4 SECS Support Trusses (Truss Type)

5 Rotary Joint Structure Beams (Truss Type)

6 Cable Reels (Column/Cable)

7 Concentrator Material (Column/Cable)

8 Extension Structure Beams (Column/Cable, Truss Type)

9 Solar Concentrator Support Structure (Boeing Thermal)

10 Busbar Harness (Boeing Thermal)

NOTE: Several SPS elements exist with masses $>10^3$ kg and frequencies of occurrence <10.

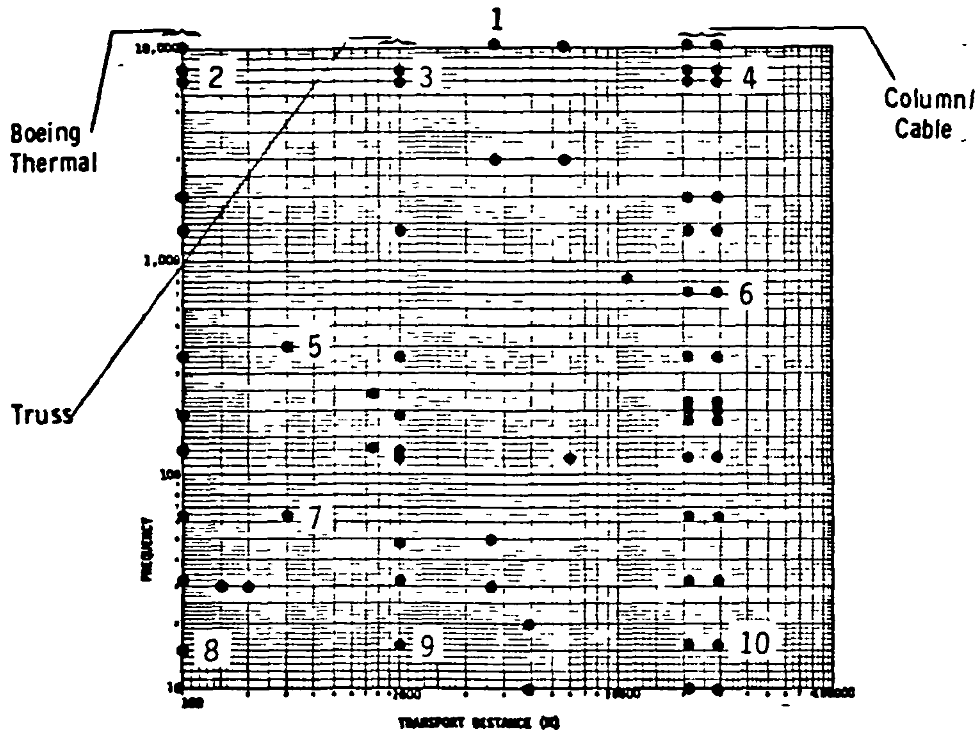


Figure V-B-3 *Element Frequency Vs Transport Distance*

<u>KEY FOR NUMBERED EXAMPLES</u>:

1 Reflector Facets (Boeing Thermal)

2 Subarrays, MPTS (Boeing Thermal)

3 Subarrays, MPTS (Truss Type)

4 Subarrays, MPTS (Column/Cable)

5 Cavity Absorber Shell Panels (Boeing Thermal)

6 Solar Cell Rolls (Column/Cable)

7 Column Beams (Column/Cable)

8 Facility Beams (Column/Cable)

9 Switch Gears, MPTS (Truss Type)

10 Switch Gears, MPTS (Column/Cable)

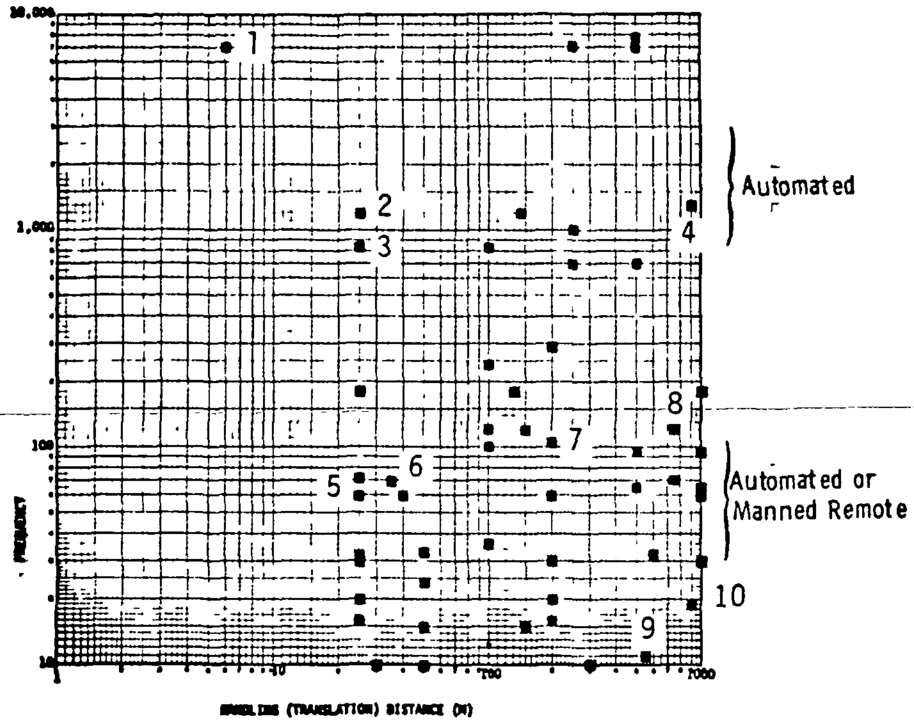


Figure V-B-4 *Element Frequency Vs Handling Distance*

KEY FOR NUMBERED EXAMPLES:

1 Electrical Conductors, MPTS Subarrays

2 SECS Support Trusses (Truss Type)

3 Secondary Tape Ends (Column/Cable)

4 Tension Rods (Truss Type)

5 Turbogenerator Sets (Boeing Thermal)

6 MPTS Frames

7 Main/Prime Cable Reels (Column/Cable)

8 Secondary Structure, MPTS

9 Radiator Segments (Boeing Thermal)

10 Radiator Frame Structure (Boeing Thermal)

C-3

1 FREE-FLYING TRANSPORTERS
- Personnel and Materials
- Materials Transporter
- Personnel Transporter

2 STRUCTURE ATTACHED TRANSPORTERS
- Personnel and Materials
- Materials Transporter
- Personnel Transporter

3 HANDLERS
- Manipulators $\geq$ 5 DOF (arm-like)
- General Purpose < 4 DOF Mechanisms

4 ALIGNERS
- Align for Joining
- Flatness
- Depth and Range

5 MATERIAL FASTENERS
- Manipulator Controlled
- EVA Controlled
- Inherent with Structure

6 ADJUSTMENT DEVICES
- Beam Positioners
- Inherent with Structure
- Cable Tensioners

7 CHECKOUT
- Input Simulators
- Data Feedback Sensors

8 MONITOR DEVICES
- Indirect Viewing
- Direct Viewing
- Instruments

9 OCSE SUPPORT EQUIPMENT
- Docking Devices
- Commodity Servicer
- Modularized Systems
- Storage Panels

10 BASE MODULES
- Core Module
- Maintenance and Repair
- Commodities Storage Module
- Assembly Jigs
- EVA Module

Categories:

A - Flight Existing   C - Commercial (One "G")
B - Flight Proposed   D - New Concept
See Appendix A

Figure V-B-5   *OCSE Inventory Tree*

FREE-FLYING TRANSPORTERS

- Personnel and Materials
  - Suited, open structure
  - Suited, closed structure
  - Shirtsleeved, closed structure
- Materials Transporter
  - Open structure
  - Closed structure
- Personnel Transporter
  - Suited, open structure
  - Suited, closed structure
  - Shirtsleeved, closed structure

STRUCTURE ATTACHED TRANSPORTERS

- Personnel and Materials
  - Suited, open structure
  - Suited, closed structure
  - Shirtsleeved, closed structure
- Materials Transporter
  - Open structure
  - Closed structure
- Personnel Transporter
  - Suited, open structure
  - Suited, closed structure
  - Shirtsleeved, closed structure

HANDLERS

- Manipulators $\geq$ 5 DOF (Arm-like)
  - Fixed Base Manipulator Long
  - Mobile Base Manipulator
  - Dexterous Manipulator
  - Dual Manipulators
- General Purpose $\leq$ 4 DOF Mechanisms
  - Fixed Base Long Boom
  - Fixed Base Telescoping Boom
  - Fixed Base Module Remove/Replace Mechanism

ALIGNERS

- Align for Joining
  - Axis on Line
    - Laser
    - Video
    - Mechanical
  - Axis Perpendicular
    - Video
- Flatness
  - Laser
  - Video
  - Transit
- Depth and Range
  - Stereo Video
  - Graphic Presentations
  - TV Reticle

MATERIAL FASTENERS

- Manipulator Controlled
  - Adhesives
  - Welding
  - Mechanical
- EVA Controlled
  - Adhesives--
    - Hot Melt
    - Ultrasonic
  - Welding
  - Mechanical--
    - Punched Material
    - Rivets
    - Self-Tap Screw
    - Clamps
- Inherent with Structure
  - Mechanical (impact, etc)

ADJUSTMENT DEVICES

- Beam Positioners
  - Manipulators
  - Remote Manned Vehicle (EOTS)
  - EVA with Special Tools
- Inherent with Structure
  - Screw Jack
  - Linear Motion Wedge
- Cable Tensioners
  - Turn Buckle
  - Cable Bender

CHECKOUT

- Input Simulators
  - Heat Source
  - Sun Source
  - Electrical Supply
  - Force and Torque
- Data Feedback Sensors
  - X-ray Welds
  - Ultrasonic
  - Electrical Continuity

MONITOR DEVICES

- Indirect Viewing
  - Video - stereo, CCD, etc
  - Photography
  - Infrared
- Direct Viewing
  - Windows in ECMs
  - Telescopes
- Instruments
  - Rad Fluid Leak
  - Contamination Monitor
  - Temp Indicators
  - Strain Gages

OCSE SUPPORT EQUIPMENT

- Docking Devices
  - Vehicle Joining Only
  - Crew and Material Transfer between Vehicles
- Commodity Servicer
  - Fluid Transfer
  - Module Replacement
  - Electrical Power Resupply
- Storage Panels
  - Manipulator EE
  - Miscellaneous OCSE
  - EVA Tools
- Modularized Systems
  - Communications
  - OCSE Tracking
  - GN&C
  - Mounting Plates
  - Lighting and Video

INTEGRATED SYSTEMS

- Structure Attached Mobile Manned Vehicle with Attached Manipulators
- Free Flying Manned Vehicle with Attached Manipulators
- Remote Manned Teleoperator Vehicle Structure Attached
- Remote Manned Teleoperator Vehicle Free Flying
- Subsystem Thermal Insulator

BASE MODULES

- Core Module
- Maintenance and Repair Module
- Commodities Storage Module
- Assembly Jigs
- EVA Module

Figure V-B-6 *OCSE Candidate Concepts*

A relatively large number of OCSE candidates were identified during the study. Many of the potential candidates were obviously significant to the study and required further detailed evaluation, while others were less significant in both functional and design terms. Therefore, it was necessary to "filter out" less attractive solutions. The OCSE identified was screened and ranked using screening parameters such as task cycles, performance flexibility, performance redundancy, size, interfaces, state-of-the-art, SRT time phasing, potential obsolescence, etc. The screened candidates resulted in the following:

- Manipulator, Fixed or Mobile Base, or Dual ≥ 5 degrees of freedom
- Docking device for joining large systems
- Manned Cherry Picker, detached to booms on structure
- Base Core Module
- Fixed-base Boom, long/extendable, ≤ 4 degrees of freedom
- Maintenance Repair Module
- Commodities Storage Module
- Personnel/Material Transporter, structure attached
- OCSE Storage Panels
- Personnel/Material Transporter, free flying
- EVA Module

More detailed results of this study are available in the final report for Contract NAS 9-15120, published by Martin Marietta in July 1977.

A follow-on effort is planned for design of selected OCSE during FY77 and FY78. The next phase would include manufacturing of the OCSE with development testing conducted in facilities at JSC in FY79.

V. SPACE CONSTRUCTION AND MAINTENANCE SYSTEMS

C. AUTOMATED CONSTRUCTION

J. C. Jones
Spacecraft Design Division

The solar power satellite (SPS) must be constructed in space; therefore, special automated construction equipment must be designed and developed. In-house and contractor studies have concluded that the primary structure of the SPS will be a truss arrangement with one or two sublevels or tiers of truss members (i.e., small truss members making up larger truss members, etc.). The basic structural material, relative to current technology, will be composites of plastic resin (thermoplastic or thermosetting plastic) and reinforcing fibers (such as graphite). Required structural properties include low coefficient of thermal expansion and high modulus of elasticity. High tensile strength will be of lesser significance.

A generally accepted construction concept is to use a "beam builder", an automated machine, to fabricate the first sublevel truss structural members from strip stock material that is stored on reels. Thus, all structural material can be transported to orbit as high density payload. An assembly jig would then be used to position a number of beam builders in the proper location, and support the beams as they are produced to allow joining of the beams to form the final SPS structure. The assembly jig would also provide for installation of all other components of the SPS, including solar blankets, etc. Construction would be automated to that level which is cost effective (i.e., automate unless a manual operation is lower in overall system cost), or to that point where automation is not technologically feasible. Besides the beam builder and assembly jig, construction equipment will include manipulators (or cranes, positioning mechanisms, etc.), beam joining mechanisms, subsystems installation mechanisms, etc.

A detailed description of a space construction experiment to develop a beam builder and the processes and techniques associated with automated space construction can be found in Section IX-B-3-b.

VI. SPACE TRANSPORTATION SYSTEM

A. SPS TRANSPORTATION SYSTEM DEFINITION

E. M. Crum
Future Programs Office

The SPS Systems Definition Study (NAS 9-15196), was contracted to the Boeing Aerospace Company under the technical management of Mr. Clarke Covington of the Spacecraft Design Division. It was augmented shortly after initiation with additional tasks related to SPS transportation and transportation system operations and the contracted effort increased by approximately one-third. The 5 month Phase I effort was completed in May 1977, and Phase II is to be completed in December 1977.

The objective for the transportation tasks added to the original study was to:

a. Increase the scope and depth of understanding of the space transportation systems necessary to support an SPS program.

b. Provide a set of transportation system requirements and reference transportation system element descriptions appropriate to the conduct of an SPS program as represented by JSC Scenario "B."

c. Identify and define analyses and tests necessary to advance the confidence level in projected SPS transportation systems performance and cost sufficient to recommended initiation of an SPS technology advancement program.

The ground rules and approach prescribed were:

a. Use existing data base.

b. Use existing OTS models and modify only as required to provide cost driver summary.

c. Define transportation systems for the different satellite power generation and construction location options.

d. Provide sufficient data on OTS options to determine weight, cost, and technical risk.

A summary of the tasks which were specified to meet the study objectives is as follows:

a. Define reference transportation system.

b. Develop SPS transportation system requirements.

c. Conduct collision analysis

d. Prepare OTV system definition.

e. Prepare LV system definition.

f. Prepare an integrated operations description.

g. Perform a cost/risk assessment.

h. Prepare an advanced technology development plan.

i. Estimate exhaust product insertion into atmosphere.

j. Analyze consumption of critical commodities.

k. Prepare briefing data.

l. Prepare separate transportation system documentation.

The results of this study activity are planned to support and complement a comprehensive SPS transportation system study to be contracted in late 1977 and which, in turn, will support the preferred concepts selection milestone in October 1978. The preliminary results presented at the Phase I review on May 5, 1977, may be summarized as follows:

a. Either a two stage ballistic or two stage winged HLLV can be developed to deploy the commercial network of SPS for a development cost of less than $10B, not including costs of the launch and recovery facilities.

b. Theoretical first unit costs for either type of vehicle is about $1B.

c. Costs per flight for either vehicle, providing about 400 tons payload in LEO, are slightly less than $8 million, or about $20/kg specific launch cost.

d. The two stage cryogenic COTV remains the best of the presently-known candidates for GEO construction of the SPS, utilizing 830 tons of propellant per flight for delivery of 400 tons of payload from LEO to GEO.

e. For LEO construction of the SPS, a "self-powered" propulsion system was characterized based upon ion thrusters utilizing argon propellant.

f. Increased understanding was attained of acceptable flight mechanics and attitude control concepts for the long-duration "self-powered" LEO to GEO transfer, including management of the satellite attitude during occulted portions of the orbits.

g. LEO construction and electric "self-power" transit to GEO provides total transportation costs of about \$650/kW compared to about \$800/kW for GEO construction. Both numbers are based on SPS specific mass of 8.9 kg/kW and launch costs of approximately \$20/kg.

h. GEO construction requires nearly twice the daily launch rate as LEO construction (14 versus 7 for 4 SPS's per year) and is thus more sensitive to potential launch cost changes.

VI. SPACE TRANSPORTATION SYSTEM

B. HEAVY LIFT LAUNCH VEHICLE

VI-B-1. Booster Engine Concept Selection

M. Lausten
Propulsion and Power Division

a. Rationale

The rationale and selection of the baseline booster engine included such factors as thrust level, engine cycle, and propellant combination.

Some studies have indicated that maximum engine thrust to weight and performance is obtained with engines in the 500K to 1 mil lbf thrust class. However, a high thrust engine (approx. 2 mil lbf) was selected so as to minimize the number of engines required for the large vehicles being considered. It is felt that minimizing the number of engines should, based upon internal combustion and jet engine history, minimize overall vehicle operational complexity.

A gas generator engine cycle was selected as having the greatest potential of satisfying the major desirable characteristics of a reusable booster engine. This includes high engine thrust to weight, simplicity, minimum cost (including development, unit, and operational), high chamber pressure capability, and scalability to very high thrust levels.

In the selection of the propellants for the engine, factors such as cost, availability, toxicity, and corrosivity make liquid oxygen (LOX) the most logical oxidizer. Selection of the fuel is another matter. Liquid hydrogen (LH_2), for example, possesses many desirable characteristics; high performance, excellent cooling capability, maximum performance at a high mixture ratio, non-corrosive, and non-toxic. However, studies have shown that its high cost and low density present major drawbacks for very large and highly reusable boosters.

While RP-1 ($CH_{1.94}$) has been used extensively as a booster engine fuel, it has some major drawbacks for a highly reusable booster. The thermal decomposition and subsequent coking of thrust chamber coolant channels has been shown to occur at coolant wall temperatures as low as 400°F. While the amount of coking at temperatures as high as 600 to 700°F appears to be acceptable for a reusable engine, these maximum wall temperatures limit the practical engine chamber pressure to something between 1500 and 2000 psia. This problem is accentuated by the fact that the typical LOX/RP-1 gas side carbon layer build-up that significantly reduces heat flux and wall temperatures at lower chamber pressures (e.g., H-1 (700 psia) and F-1 [980 psia] engines) does not maintain itself for chamber pressures above approximately 1500 psia.

In order to circumvent the problems associated with RP-1 cooling without acquiring the potential problems associated with using LOX as the chamber coolant, other potential fuels were considered.

After a limited survey, propane (C_3H_8) was selected as having the potential to satisfy the major desirable characteristics of a reusable booster fuel while specifically overcoming the major drawbacks of RP-1 and LH_2. In particular, propane does not experience any thermal decomposition below 860°F, thus potentially allowing maximum engine chamber pressures on the order of 3000 psia. Propane possesses several other potentially desirable characteristics:

(1) It is a gas at standard temperatures and pressures and postflight purges could be minimized as compared with RP-1 with its very low vapor pressure.

(2) Heated propane could provide autogenous pressurization (not possible with RP-1).

(3) It has an unusually wide subcooling range (normal boiling point = -43.7°F and freezing point = -305.9°F).

(4) Its freezing point is below the normal boiling point of LOX thus potentially eliminating the requirement for insulation on common bulkhead tankage.

(5) The low freezing point of propane should eliminate injector design problems associated with LOX freezing of RP-1 in the injector manifolds and combustion chamber.

b. Engine Characteristics

A detailed regenerative cooling analysis was not conducted for LOX/propane. However, the results from RP-1 and methane (CH_4) analyses indicate that a chamber pressure of approximately 3000 psia could be achieved within an acceptable maximum chamber wall temperature and coolant pressure drop. The prediction of actual maximum engine heat flux is very difficult at best. However, a simplified analysis was conducted to obtain relative heat flux data. The analysis showed that the heat flux for LOX/propane and LOX/RP-1 were essentially equal (propane 5% higher than RP-1) and that the heat flux for LOX/propane was 20 percent less than for LOX/LH_2 for the same thrust and chamber pressure. The analysis also showed that the high thrust (large throat diameter) of the LOX/propane engine reduced its heat flux relative to the SSME (Space Shuttle Main Engine, LOX/LH_2, 3000 psia, and 470 KLBF thrust) by some 40 percent. In particular, the maximum chamber heat flux for the LOX/propane engine should be less than 50 percent of that experienced by the SSME.

The LOX/propane engine cycle was assumed to consist of individually powered oxidizer and fuel pumps, thus permitting operation

at speeds corresponding to maximum efficiency without requiring life limiting and complex gearing. The pumps were assumed to be powered by two stage turbines operating at temperatures consistent with long life (1660°F). The turbin exhaust gases were assumed to be injected into the main 40:1 expansion ratio nozzle so as to maximize performance. The flows for the single stage main pumps were increased by 10 percent to account for hydraulic powering of low speed oxidizer and fuel boost pumps (e.g., SSME LOX pumps).

The propane was assumed to be loaded at LOX temperatures (-297°F) so as to minimize propellant tank weight, to maximize regenerative cooling capability, and to minimize turbopump weight and power. The nominal engine mixture ratio was selected so as to maximize engine performance. However, being that the oxidizer is much cheaper than the fuel, engine performance at high mixture ratios was generated to support studies to determine vehicle operating characteristics corresponding to minimum overall cost. The major engine predicted characteristics at nominal operating conditions are summarized in Table VI-B-1.

TABLE VI-B-1

LOX/PROPANE ENGINE CHARACTERISTICS

ENGINE

Thrust, vacuum (mil lbf)	2.00
Thrust, sea level (mil lbf)	1.79
Specific impulse, vacuum (lbf-sec/lbm)	340.0
~~Specific impulse, sea level (lbf-sec/lbm)~~	~~304.1~~
Mixture ratio (wo/wf)	2.68
Flow rate, oxidizer (lbm/sec)	4284.0
Flow rate, fuel (lbm/sec)	1598.0
Nozzle expansion area ration (AE/AT	40.0:1
Nozzle diameter (in)	135.0
Power head diameter (in)	125.0
Engine length (in)	230.0
Weight, dry (K lbm)	20.0
Thrust/weight dry (lbm)	100.0
MAIN CHAMBER	
Chamber pressure (psia)	3000
Mixture ratio (wo/wf)	3.07
Combustion efficiency C* (PCT)	97.5
Maximum heat flux (PCT of SSME)	50.0
Throat diameter (in)	20.8
GAS GENERATOR	
Chamber pressure (psia)	3000
Mixture ratio (wo/wf)	0.30
Temperature (^{O}R)	1660
Total flow rate (PCT of engine total)	5.0
MAIN TURBOPUMPS	
Density, oxidizer (lbm/ft^3)	71.4
Density, fuel (lbm/ft^3)	46.3
Flow rate, oxidizer (KGPM)	29.62
Flow rate, fuel (KGPM)	17.04
Pressure rise, oxidizer (psid)	4000
Pressure rise, fuel (psid)	5000
Horsepower, oxidizer (KHP)	81.8
Horsepower, fuel (KHP)	60.7

VI. SPACE TRANSPORTATION SYSTEM

B. HEAVY LIFT LAUNCH VEHICLE

VI-B-2. Launch Vehicle Design Analysis

J. Hondros
Engineering Analysis Division

The purpose of this section of the report is to present new results and data that are improved from the 1976 SPS documentation. The major differences in the designs are reduced weights for the winged 1-million pound payload systems. The major weight reductions were brought about by removal of air-breathing engine systems, much improved weight estimating techniques, and reduction of the 20% contingency to a 10% contingency.

An evaluation of 16 conceptual configuration designs was conducted and documented as shown in Table VI-B-2. The matrix of configurations contains various combinations of payloads, payload density, winged and ballistic, composite materials, booster engines and second stage engine changes as well as variations in series and parallel burn of the stages. The design document numbers are identified on Table VI-B-2 and can be obtained on request.

The gross results of this analysis are as follows:

a. Payload density variations of 30 lbs/ft^3 to 10 lbs/ft^3 cost 210K in stage inerts, 1.4M pounds in propellant, and 120K dollars per flight.

b. Design for a reusable or foldup interstage. A weight margin of 177,000 pounds is available for this task. The margin consists of a 44K nose, a 58K interstage and 75K lead ballast for aerodynamic trim. In excess of 45,000 tons of aluminum is saved for a 1500 flight profile.

c. Series burn vehicles provide more performance per pound of gross weight. The performance is obtained by engine expansion ratio increases available for series burn. Series systems save 1.8M pounds of gross weight and about 730K dollars in propellant cost per flight.

d. Tri-propellant booster engines give a reduction of almost 1M pounds in gross weight; however, they cost between 100K and 270K dollars more in propellant cost per flight.

e. Complex LOX/hydrogen vehicles have a 3.5M pound reduction in vehicle gross weight as compared to a LOX/propane system but, LOX/hydrogen systems cost 2 million dollars per flight more in propellant cost.

f. A 20% weight reduction for composite materials application in the vehicle saves almost 2 million pounds in gross weight and about 100K dollars per flight. This is an area considered for technology advancement with a weight and cost payoff.

g. Payloads should be designed large. Large vehicles in the current study are more efficient per pound of payload delivered.

h. A short cost analysis of propellants for delivery of a 1M pound payload was made on LOX/propane and LOX/hydrogen booster systems. Assuming 2 cents/pound for LOX and 5.3 cents/pound for propane, hydrogen must be delivered for 45 cents/pound. If propane costs escalate to 15 cents/pound, hydrogen must be delivered at 85 cents/pound. Current cost of hydrogen for Shuttle is $1.85/pound and probably will be prohibitive in cost unless some technology can reduce the product cost.

The baseline JSC in-house study launch vehicle size and performance is presented in document EDIN EX 338-76, Appendix VI-APP-A.

ENGINEERING ANALYSIS DIVISION EX

BRANCH EX42 DATE 1/1/77

BY Hondros PLOT NO

TABLE VI-B-2
CONFIGURATION MATRIX

CASE	VEHICLE DESCRIPTION							COMMENTS	DESIGN DOCUMENT NUMBERS
1	W/W,	S.B.	1M# Pld;	30#/ft^3 P.D.	Exp	U.SSME	B-LOX/Propane	(Baseline)	EDIN EX-333-76
2	W/W;	S.B.	1M# Pld;	20#/ft.^{3} P.D.	Exp	U. SSME	B-LOX/Propane		EDIN EX-341-76
3	W/W;	S.B.	1M# Pld,	10#/ft.^{3} P.D.	Exp	U. SSME	B-LOX/Propane		EDIN EX-345-76
4	W/W;	S.B.	500K Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/Propane		EDIN EX-350-76
5	W/W;	S.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp	U. SSME	B-LOX/Propane/H_2	Tripropellants	EDIN EX-012-77
6	W/W;	S.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp	N2E;	B-LOX/Propane	New SS Engine	EDIN EX-340-76
7	W/W,	S.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/Propane	Composite Material	EDIN Ex-351-76
8	W/W;	S.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp	U. SSME	B-LOX/H_2	6:1 Mixture	EDIN EX-359-76
9	W/W,	S.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/H_2	7:1 Mixture	EDIN EX-358-76
10	W/W;	S.B.	500K Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/H_2	7:1 Mixture	EDIN EX-356-76
11	W/W;	S.B.	1M# Pld;	30#/ft.^{3} P.D.	RET	U. SSME	B-LOX/Propane		Analysis
12	B/B	S.B.	1M# Pld;	30#/ft.^{3} P.D.		U. SSME	B-LOX/Propane		Unavailable
13	W/W;	P.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/Propane		EDIN EX-014-77
14	W/W;	P.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/Propane	LOX Crossfeed	EDIN EX-017-77
15	W/W;	P.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/Propane/H_2	Tripropellants	EDIN EX-018-77
16	W/W;	P.B.	1M# Pld;	30#/ft.^{3} P.D.	Exp.	U. SSME	B-LOX/Propane/H_2	LOX/H_2 Cross-feed	EDIN EX-019-77

W/W - Winged/Winged
S.B. - Series Burn
Exp. - Expendable Interstage
P.B. - Parallel Burn
U. SSME's - Uprated SSME'S
P.D. - Payload Density
N2E - New 2nd Stage Engines
RET - Retainable Interstage
B/B - Ballistic/Ballistic
B-Booster

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VI. <u>SPACE TRANSPORTATION SYSTEM</u>

B. HEAVY LIFT LAUNCH VEHICLE

3. <u>Modified Single Stage to Ortit Concept</u>

Jack Funk
Technology Dev. Office-MPAD

SUMMARY

The modified single stage to orbit heavy lift launch vehicle configuration (MSSTO) was evaluated for 1 000 000 pounds of payload delivered to a 270 n.mi. circular orbit using two main propulsion engine types one fueled with hydrogen and the other fueled with propane. The system was evaluated for the engine combination which provided the lowest cost for launch expendables using $20, $1, 18¢, and 10.2¢ per pound, respectively, for expendable tank, liquid hydrogen, propane, and liquid oxygen.

The results indicate that the minimum expendable cost occurs with 25 percent of the lift-off thrust being fueled with hydrogen and 75 percent being fueled with propane. The expendable cost per 1 000 000 pound payload is about $6 000 000 or $6 per pound of payload.

The MSSTO had a gross lift-off weight of 26 795 000 pounds. The lifting body orbiter measured 315 feet in length and 194 feet in width. The external hydrogen tank was one and one half times the dimensions of the Space Shuttle external propellant tank and measured 242.6 feet in length and 41.6 feet in diameter.

A comparison between the sizes of the modified single stage to orbit and the two stage heavy lift launch vehicles is shown in figure VI-B-1.

I GENERAL DESCRIPTION

The modified single stage to orbit heavy lift launch vehicle (figure VI-B-2) consists of a reusable orbiter vehicle and expendable fuel tank. The orbiter vehicle includes all of the engines, subsystems, payload bay hydrocarbon fuel tank and oxidizer tank. The drop tank contains only the liquid hydrogen fuel and is carried to orbit where it is staged for disposal using the same technique developed for disposal of the Shuttle external tank. The single propellant drop tank is simpler than multi-propellant tanks and is designed for light weight and low cost. To aid in the light weight design, the launch trajectory is restricted to low dynamic pressures and accelerations. The nominal trajectory angle of attack is restricted to zero through the maximum dynamic pressure region.

The modified single stage to orbit vehicle can deliver more payload to orbit for a given gross lift-off weight by expending the fuel tank than can a full

reusable SSTO. This technique for payload improvement was studied during the phase B Shuttle studies and resulted in significant payload gains over the fully reusable system.

The expected advantages of the modified single stage to orbit launch vehicle over the two stage vehicle are:

1. Reduced development cost by elimination of the booster.

2. Reduced first unit cost by the purchases of one vehicle instead of two.

3. Reduced facilities cost by elimination of the downrange landing site and transportation system required to return the booster to the launch site.

4. Simplified launch operations by elimination of the booster staging, downrange landing, booster transportation to launch site, and elimination of inflight start of the orbiter engines.

5. Launch site flexibility: because of the downrange landing requirement of the booster the choice of launch sites for the baseline system is very limited, whereas the MMSTO can be launched from almost any location by changing the main engine cutoff conditions for tank disposal.

The major disadvantage of the MSSTO is the cost of the external hydrogen tank. The development of a low cost hydrogen tank is essential to low cost operation of the MSSTO.

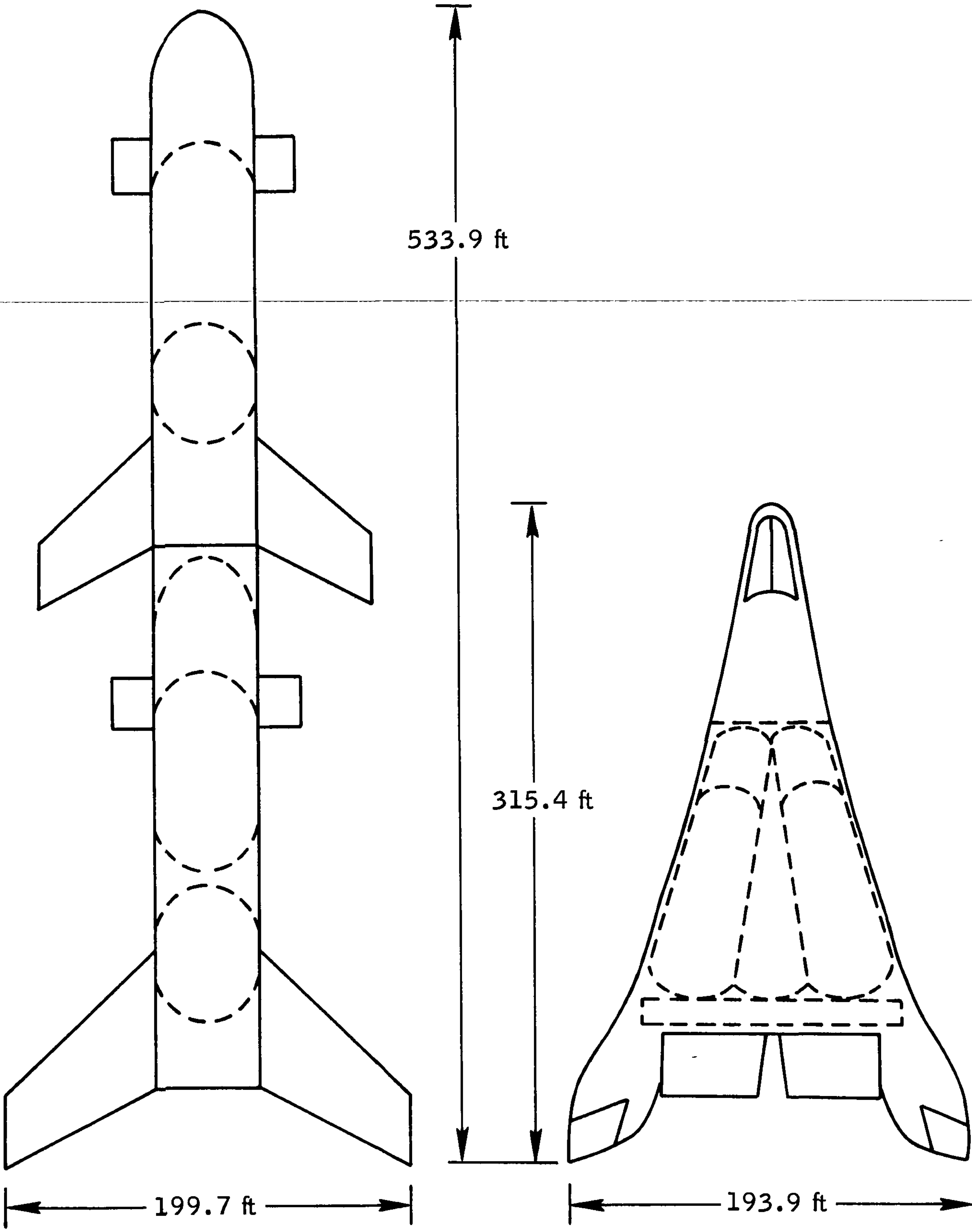

Figure VI-B-1 - Comparison of modified single stage to orbit launch vehicle and two stage launch vehicle.

Payload 1 000 000 lb
Glow 26 789 000 lb

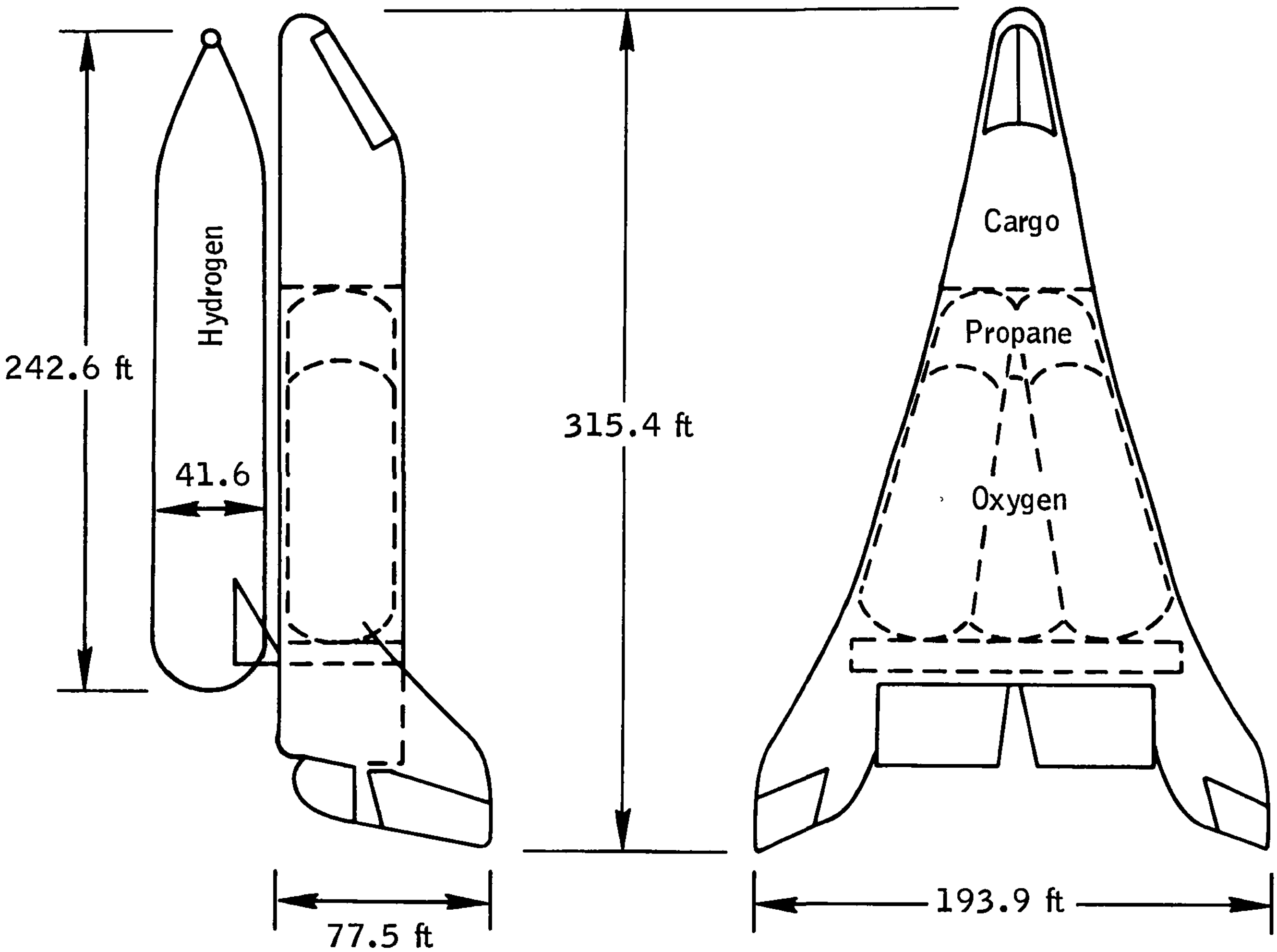

Figure VI-B-2 - Modified heavy lift launch vehicle mixed mode.

II MODIFIED SINGLE STAGE TO ORBIT SYSTEM CHARACTERISTICS

Propulsion - Main

Rocket engines using oxygen as the oxidizer and both hydrogen and propane as fuels were considered for the main propulsion. The propane engine uses hydrogen as an engine coolant. The characteristics of these engines as supplied by the Power and Propulsion division are given in table VI-B-3. One third of the engines are gimbaled.

The characteristics of the propellants are given in table VI-B-4.

Tankage and Propellant System

The propellants for ascent are carried in a single tank system. The oxygen and propane tanks are integral to the entry vehicle and act as the primary airframe and load carry structure for launch and entry. The hydrogen fuel tank is mounted external to the entry vehicle and is staged for disposal at the end of the main engine burn. Orbit insertion is accomplished with the orbit maneuvering system (OMS). The oxygen tank and its entry heat protection are aerodynamically shaped to the lifting body configuration (reference 1) using the multilobe tank design from reference 2.

The external hydrogen tank shape is scaled from the shuttle external tank profile and shuttle-tank aerodynamics are used in drag calculations for the launch trajectory. The expendable hydrogen tank is designed for low cost and light weight. The tank has a monocoque structure of 2219-T87 aluminum sheet. External hydrogen drop tank structural analysis performed during the phase B shuttle studies concluded that if the tank walls are designed for internal pressure, the tank is capable of sustaining all ascent load conditions without the requirement of additional stiffening. Also, the drop tank can be subject to handling from its extremities without damage through all stages of assembly if the tank is internally pressurized to 2 psi. A significant weight penalty results, however, if the tank is required to be handled unpressurized.

It is expected that these results will hold true for the much larger drop tank of the modified single stage to orbit configuration.

The ullage pressure required for engine start of 25 psia is at sea level where the ambient pressure is about 15 psia. At the time of maximum dynamic pressure the internal pressure should be down to 20 psia with an ambient pressure of about 3.5 psia. The critical design condition, therefore, is expected to be at 3.0 g with an ullage pressure of 20 psia and a 50% full tank. The pressure on the aft dome will be about 33 psia. To simplify the weight analysis, the structural weight was based on an average wall pressure of 25 psia with a factor of safety of 1.5 on the ultimate strength of 2219-T87 aluminum at room temperature of 63000 PSI. The density of this material is 0.102 lbs/in^3.

TABLE VI-B-3

MAIN PROPULSION SYSTEM ENGINE CHARACTERISTICS

	SSME	H2 COOLED PROPANE	DUAL EXPANSION	SINGLE EXPANSION
PROPELLANTS	O_2/H_2	O_2/C_3H_8	O_2/H_2	O_2/H_2
ENGINE CYCLE	STAGE COMBUSTION	GAS GEN.	GAS GEN.	GAS GEN.
COOLANT	H_2	H_2	H_2	H_2
CHAMBER PRESSURE	3250	6000	6000	6000
MIXTURE RATIO	6	3.29	7	7
NOZZLE AREA RATIO	77.5	70	60/270	60
THRUST VACUUM	512K	VARIABLE	VARIABLE	VARIABLE
SPECIFIC IMPULSE VACUUM	455.2	357.4	437/463	437
THRUST AREA RATIO	.01261	.005674	.007061/ .02473	.007061
ENGINE THRUST/WEIGHT*	80.76	100.0	70.8	90.0

*VACUUM THRUST/DRY WEIGHT

TABLE VI-B-4

PROPELLANT CHARACTERISTICS

	O_2	H_2	C_3H_8
LIQUID DENSITY (lb/ft^3)	71.3	4.42	
STORAGE TEMPERATURE (deg F)	-297.0	-420.0	-45.0
COST ($/lb)	.102	1.00	.180

An equation developed for the weight to volume ratio of a cylindrical tank with spherical domes is given below.

$$\frac{W}{V} = FPd \frac{(3+6K)/S}{2+3K}$$

Where:
P is tank pressure
d is material density
S is material strength
K is tank length to diameter ratio
F is design safety factor

The tank pressure, material density and ultimate strength are given above. The tank length to diameter ratio is 3.82 and the factor of safety is 1.5. In addition, a 10% weight factor was added for sheet gage tolerance. The weight to volume ratio for the tank structure is

$$\frac{W}{V} = 1728*1.10*1.50*0.5*0.10*\left(\frac{3+6*3.82}{2+3*3.82}\right) /63000 = 0.222 \text{ lb/ft}^3$$

The entire tank is covered with 0.75 inch thick polyurethane foam (2.0 PCF) with 0.125 inch added for coating errors. An additional 0.104 PCF was added for waterproofing and flame retardant. In the area of interference heating between the orbiter and tank and on the aft cone, 0.25 inch of 30 PCF ablator was added. The area of interference heating was estimated as 30% of the barrel surface.

The orbiter-tank attachment structure weight was estimated as 8% of the tank weight and includes stiffening of the tank wall in the vicinity of the attach points.

Sizing and loading of the propellant tanks is biased so that oxygen depletion occurs prior to hydrogen depletion. The 3 flow rate error is 1% for each engine. The total flow rate error is the root sum square of the flow rate errors of the operating engines. This is integrated along the trajectory to obtain the hydrogen bias.

The main propulsion propellant system is pressurized by gaseous oxygen and hydrogen bled from the main engine. Pressurization for engine start is provided through vent lines from ground supply.

The integral liquid oxygen tank weight was estimated using the multilobe propellant tank weight projections from reference 2. The value used is 0.52 lbs/ft^3.

<u>Thermal Protection System</u>

The aerodynamic shape for the entry vehicle is a scaled version of the lifting body entry vehicle of reference 1. The thermal protection system

given in reference 1 averaged 2.28 lbs/ft^2 of surface area. The thermal protection for the body of the baseline single stage to orbit vehicle of reference 2 averages 2.247 lbs/ft^2. Both heat protection systems were similar in concept consisting of RSI mounted subpanels mounted on aluminum standoff rails. They differ primarily in the type of RSI titles and subpanel material used. The difference in weight, however, is only 1.5%. The heat protection system weight estimates are therefore based on the 2.28 lbs/ft^2 value from reference 1. (The shuttle TPS averages 1.675 lbs/ft^2.)

The heat protection from reference 1 was sized for 1100 n.mi. crossrange on entry. The entry trajectory was shaped to minimize the TPS weight. Peak temperatures were estimated to be 2610 deg F on the nose cap, 1980 deg F on the body leading edge, 2080 deg F on the fin leading edge, and 2050 deg F on the lower surface. The TPS limits the structural temperature to 300 deg for aluminum structure and 600 deg F for titanium structure.

The only nonreusable TPS is the flexible flame curtain used to seal the base area aound the gimbaled engines.

Landing Gear

The landing gear is an advanced design by Boeing Aerospace from reference 3. The tri-cycle gear weight savings have been accomplished in three main areas, lowered requirements, improved structural materials, and a simplified design. The activation system is designed for extension only with gravity and air loads aiding. Maximum advantage is taken of composite and 350 ksi steels.

The weight estimate for this landing gear is 2.8% of the landed weight.

Tail Groups

The tail groups consist of the fin, rudder, upper flap, lower flap and auxiliary control surfaces. The primary structure material is titanium. The weight of the tail group is estimated as 6.13% of the vehicle dry weight (reference 1).

Thrust Structure

The weight estimating relation for the thrust structure is

$$W = 3.0 \times 10^{-4} (F_{VAC})^{1.15}$$

Weights from the above equation agree with the thrust structure weights for the Saturn SIVB stage, the shuttle orbiter, the Saturn SIC stage and calculation in reference 1. The above equation results in weights that are higher than the Titan III stage 1 and lower than the Saturn SII stage. The above equation is an excellent representation of the current technology in thrust structure design. The equation is used to estimate the thrust structure for the engines and for the payload mounting on top of the propellant tanks.

Payload Compartment Structure

The payload compartment is in the nose of the airframe, figure VI-B-1. The prime function of the payload compartment is to act as an aerodynamic shroud on launch which is recoverable. Launch loads from the payload are carried by a thrust structure mounted on top of the propane tank and not by the bay structure. The payload thrust structure weight is estimated according to the weight equation given in the section on thrust structure.

The vacuum thrust in the above equation is replaced by the maximum launch acceleration times the payload weight. Package requirements for mounting the payload on the thrust structure are charged to payload.

The payload bay structure weight was estimated as a linear function of bay volume using the average airframe structural weight of the lifting body design from reference 1 of 0.362 lbs/ft^3. The payload bay volume was based on an average payload density of 10 lbs/ft^3.

Orbit Maneuvering System

The propellant for the orbit maneuvering system is liquid oxygen and liquid hydrogen. The engine system and propellant weights estimates are based on performance and weight data for the RL-10 rocket engine. The propellant tank weights are estimated at 2.0 lbs per cubic foot. The initial engine thrust to vehicle weight ratio for engine weight estimates is 0.1g. The RL-10 engine thrust was 41.67 times the engine weight, and the specific impulse was 444.0 sec. The propellant requirements and tank volume were based on the delta V required to maneuver from main engine cutoff to 270 n.mi. circular orbit and deorbit with a 10% fuel reserve. The propellant mixture ratio for OMS engine is 7:1.

Reaction Control and Other Systems

The reaction control, prime power, electrical, hydraulic, surface control, and avionics system weights were estimated as a percentage of the dry weight as follows.

Reaction Control System	1.5
Reaction Control Propellant	1.6
Prime Power	1.1
Electrical	1.1
Hydraulic	1.1
Surface Controls	6.13
Avionics	1.4

Growth Uncertainty

The growth uncertainty is calculated at 10% of the dry weight.

Residual and Unusable Fluids

The oxygen tank residuals are calculated as 0.219% of the liquid oxygen weight and the hydrogen tank residuals as 0.559% of the liquid hydrogen weight. These values were obtained from the shuttle external tank weight statement. The unusable fluid in the engine lines is 0.1% of the engine thrust. The unusable fluids at main engine cutoff (MECO) was calculated according to the number of engines operating at MECO. The remainder of the engine line fluids are dumped as the engines are shut down during launch and are included in the inflight losses.

Reserve Fluids

Ten percent of the OMS propellant is reserve. The RCS propellant is expected to exceed the nominal mission requirements. Based on shutle data, it is estimated that the RCS reserve propellant is about 50% of the total. These reserves are listed in the propellant budgets of their respective systems.

Entry Vehicle and External Tank Geometry

The aerodynamic entry vehicle is based on the lifting body configuration from the phase B shuttle studies, reference 1. The geometric characteristics of the configuration are given in table VI-B-5.

The external hydrogen tank is based on the shuttle external propellant tank configuration. The geometric characteristics of the external hydrogen tank are given in table VI-B-6.

Volume Allotments

The volume allotments for the various systems are given in table VI-B-7.

TABLE VI-B-5

ORBITER GEOMETRY

LENGTH (ft)	149.6 * SF
SPAN (ft)	92.0 * SF
HEIGHT (ft) - GEAR UP	36.8 * SF
GEAR DOWN	49.0 * SF
PLAN FORM AREA (ft^2)	6846 * SF ** 2
BASE AREA (ft^2)	1229 * SF ** 2
WETTED AREA, INCLUDING BASE (ft^2)	18944 * SF ** 2
MOLD LINE VOLUME (ft^3)	97600 * SF ** 3

SF = Orbiter scale factor

TABLE VI-B-6

TANK GEOMETRY

LENGTH (ft)	157.09	*SFET
DIAMETER (ft)	26.96	*SFET
SURFACE AREA TOTAL (ft^2)	10524.	*SFET**2
OGIVE (ft^2)	2091.	*SFET**2
BARREL (ft^2)	9475.	*SFET**2
AFT DOME (ft^2)	958.	*SFET**2
VOLUME TOTAL (ft^3)	78431.	*SFET**3
CROSS SECTION, AREA (ft^2)	570.86	*SFET**2

SFET = TANK SCALE FACTOR

THERMAL PROTECTION

3/4 inch poly-urethane foam (2 PCF) over entire tank; 0.125 inch thickness uncertainty; 0.104 PCF waterproofing and flame retardant; 1/4 inch 30 PCF ablation on 30% of barrel surface for orbiter tank interference and aft dome for base flame impingement.

TABLE VI-B-7

ORBITER SYSTEMS VOLUME ALLOTMENTS

	Fraction of total
Air Frame Structure, Tank Walls and TPS	.09867
Wheel Wells	.01865
Equipment and ACS	.01025
Prop Lines and Tank Support	.01393
Thrust Structure	.04734
Main Engines and OMS Engines	.06045
Base Between Engines	.04908
Lower Flap	.01363
Fin Rudder and Aux Surfaces	.04436
Flap Stowage	.04375
Internal Propellants & Payload	.48970
Unoccupied	.11019
Total	1.0000

III AERODYNAMICS

Drag Characteristics

The drag coefficient as a function of Mach number is given in table VI-B-8 for the lifting body and the external tank. The forebody drag coefficient is given for the lifting body and this is combined with the power on base pressure to obtain the total drag. The drag coefficient for the external tank is power off total drag. It was assumed that there is no power on effect on the base of the external tank.

The drag calculations are based on a reference platform area for the lifting body of 453.2 square meters (4878 feet squared) and is varied according to the square of the scale. The vehicle scale is determined by the LOX volume and the system volume requirements given in table VI-B-8. The lifting body scale factor is the cube root of the ratio of the total volume to the reference volume of 2738.2 cubic meters (96 700 cubic feet).

In a similar manner the external hydrogen tank drag is based on the shuttle external tank shape scaled to contain the required volume of liquid hydrogen. The reference area for the external tank is 55.56 square meters (598 square feet) and the reference volume is 2220.9 cubic meters (78 431 cubic feet).

The power on base force was calculated from the power on base pressure using the total area of the base of the lifting body minus the area of the engine bells. As engines were turned off, the force was reduced by the percentage of engines not operating. The power on based pressure data given in table VI-B-8 were calculated from the shuttle base force calculations Rockwell International Space Division report SD74-SH0206-2H.

TABLE VI-B-8

LAUNCH VEHICLE DRAG CHARACTERISTICS

Lifting Body		External Tank	Lifting Body Power on Base Pressure	
M	C_{AF}	C_A	ALT(ft)	PSI
0.0	.055	.409	0	0
0.6	.055	.409	2 500	-.508
0.7	.056	.430	7 500	-.831
0.8	.063	.454	15 000	-1.154
0.9	.080	.475	20 000	-1.039
1.0	.111	.663	27 500	-.669
1.1	.134	.774	35 000	.046
1.2	.147	.819	45 000	.716
1.4	.155	.850	55 000	.970
			60 000	1.016
1.6	.157	.846	70 000	.970
1.8	.153	.808	80 000	.808
2.0	.148	.772	90 000	.646
2.4	.140	.707	100 000	.462
3.0	.130	.608	120 000	.254
4.0	.122	.500	140 000	.185
5.0	.117	.464	160 000	.185
25.0	.117	.464	500 000	.185

IV REFERENCE MISSION

The sizing analysis and trade studies are based on delivery of a payload to a 270 n.mi. circular orbit and return to a launch site at 5.5 degrees latitude as indicated in figure VI-B-3. The 5.5 degrees latitude launch site was chosen to agree with the other launch vehicle studies.

The lift-off thrust to weight ratio is 1.30. This value was chosen in order to keep the maximum dynamic pressure low. The maximum acceleration on launch is restricted to 25 g. The main engines are shut down sequentially as the vehicle exceeds the maximum acceleration. The propane engines were shut down first and then the hydrogen engines. A preliminary analysis indicated that 2.5 g value would provide more payload for a given gross lift-off weight than 3.0 g.

The main engines cutoff is at an altitude of 364 508 feet, flightpath angle of 0.5 degrees, and a velocity of 25 665 feet per second. This results in a tank impact roughly 180 degrees down range from the launch site for a ballistic trajectory. The orbit maneuvering system is used to transfer from MECO to a 270 n.mi. circular orbit and for deorbit.

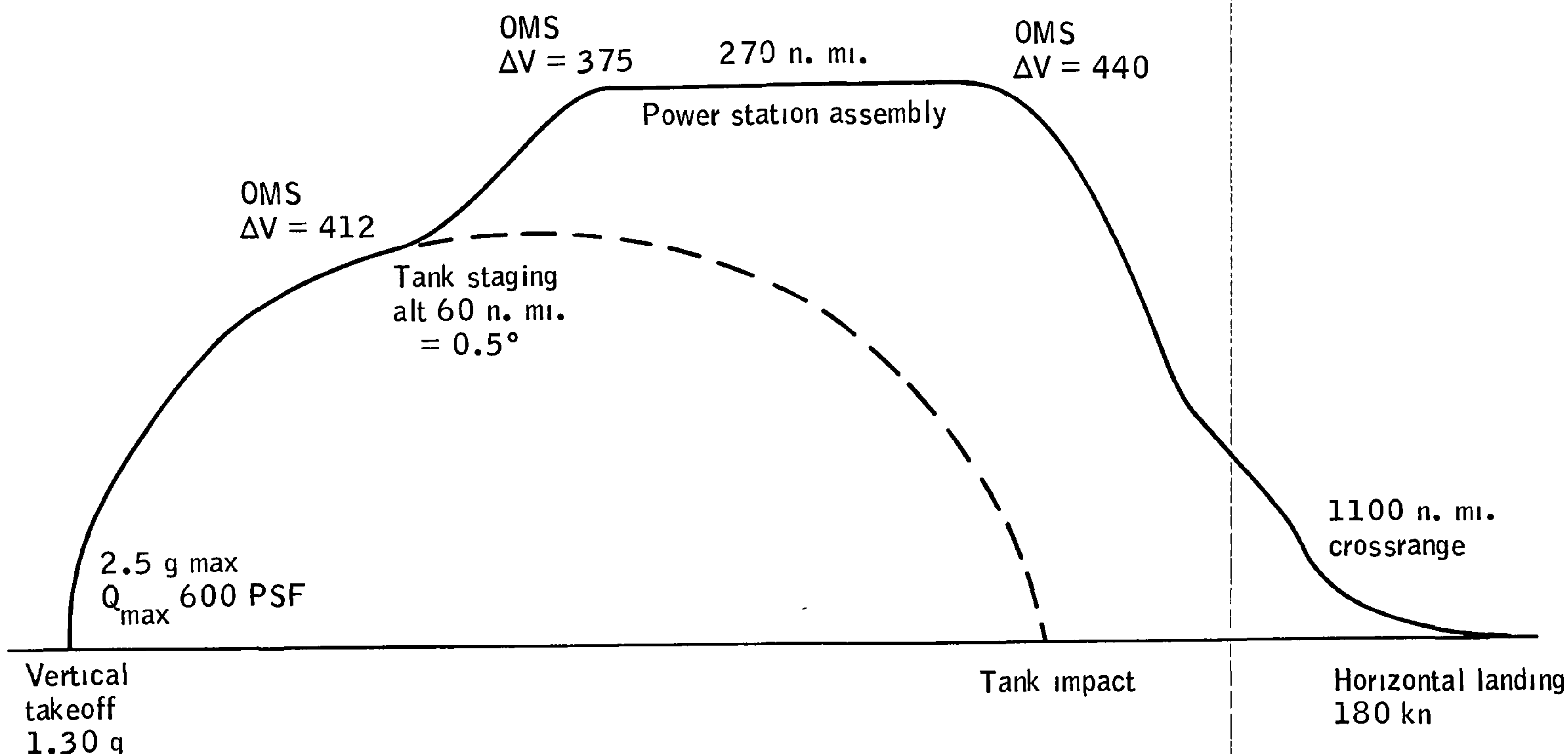

Figure VI-B-3 - Mission profile.

V ANALYSIS

Trajectories and vehicle size were evaluated for combinations of LOX/LH2 and LOX/C3H8 engines. Twenty-one (21) engines all having equal vacuum thrust at lift-off were used in the analysis. These engines were then scaled in size to provide 1 000 000 pounds of payload. In the case of the dual expansion engine the vacuum thrust for the lower expansion ratio was the same as the vacuum thrust of the hydrocarbon engines.

In addition, vehicle sizes were evaluated for a LOX/C3H8 engine with a thrust to engine weight of 150. There are considerable differences between the engine technology projections given in table VI-B-3 and those being projected by the Langley Research studies, reference 2. These data show the advantages of engine technology improvements which reduce weight.

Cost of the major launch expendables were calculated based on \$20 per pound for the expendable hydrogen tank, \$1 per pound for hydrogen, \$.102 per pound for LOX and \$.18 per pound for propane.

The results of the analysis are summarized in figures VI-B-4, 5, 6, and 7. In figVI-B4 the gross lift-off weight and dry weights are shown as functions of the number of hydrocarbon engines. For the heavier hydrocarbon engine, thrust to engine weight of 100, the minimum GLOW and minimum dry weight are for the all hydrogen vehicle. However, the minimum expendable cost, fig. VI-B-4, occurs when 2/3 of the thrust is from the hydrocarbon engines, that is, 7 LOX/LH2 and 14 LOX/C3H8 engines. The lighter propane engine shows a minimum in both dry weight and cost. The minimum dry weight occurs with about 17 hydrogen fueled engines. The minimum cost of expendables is with 5 hydrogen fueled engines.

The most economical system for expendables appears to be about 25% of the thrust from hydrogen and 75% from propane. The baseline system has 5 hydrogen fueled engines and 16 propane fueled engines.

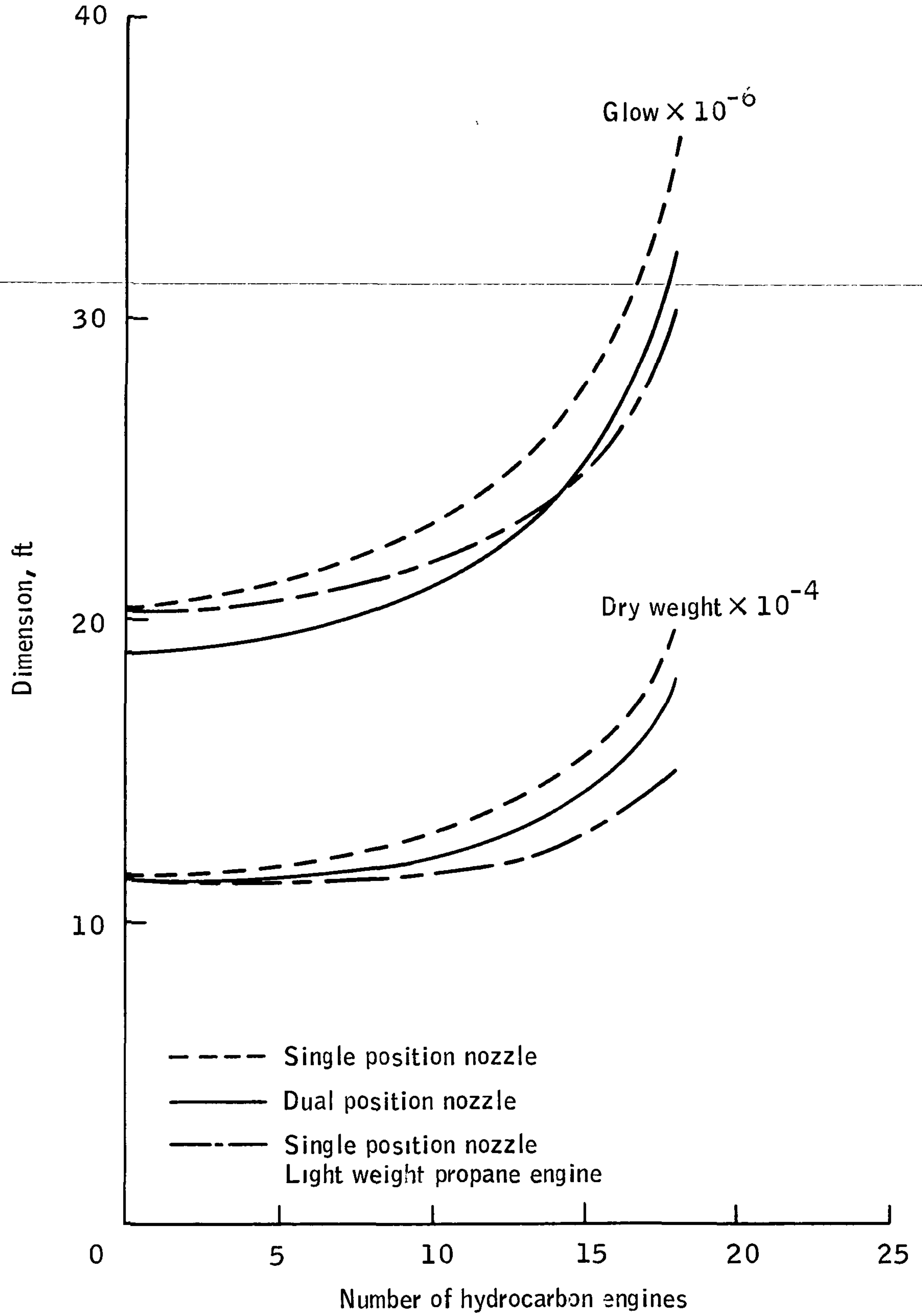

Figure VI-B-4.- Mixed mode parametric data.

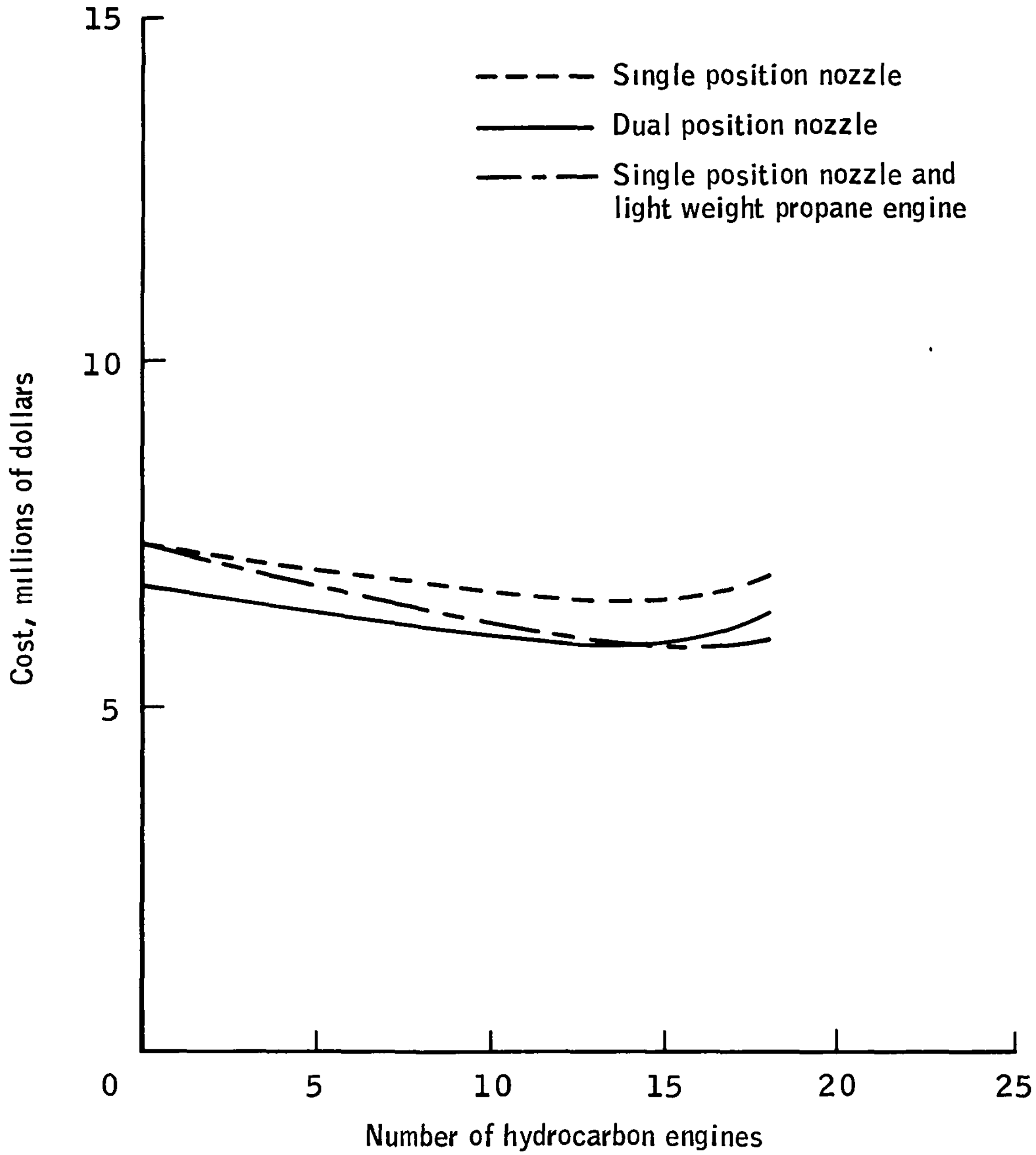

Figure VI-B-5.- Mixed mode expendables cost data.

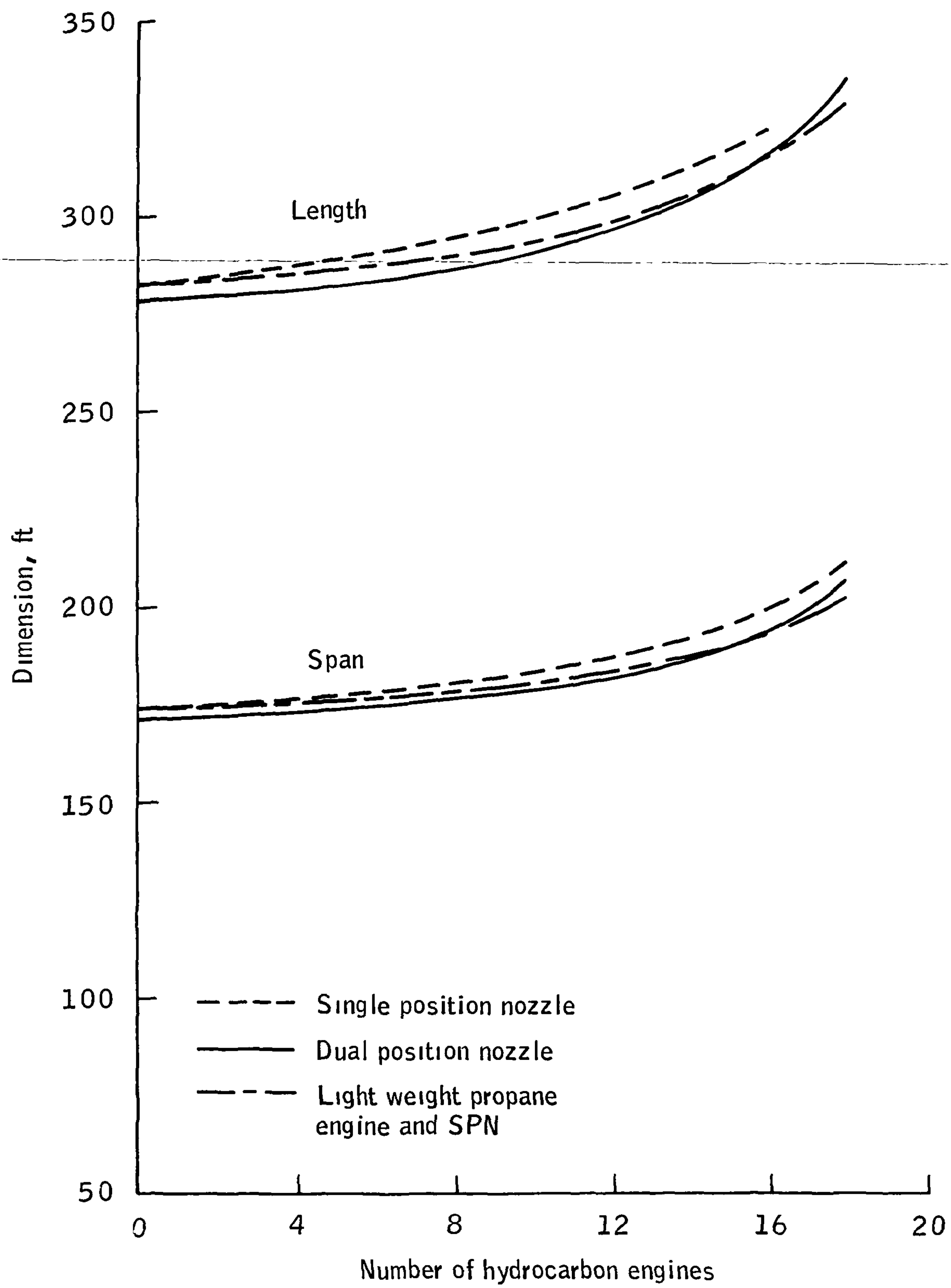

Figure VI-B-6.- Orbiter dimensions.

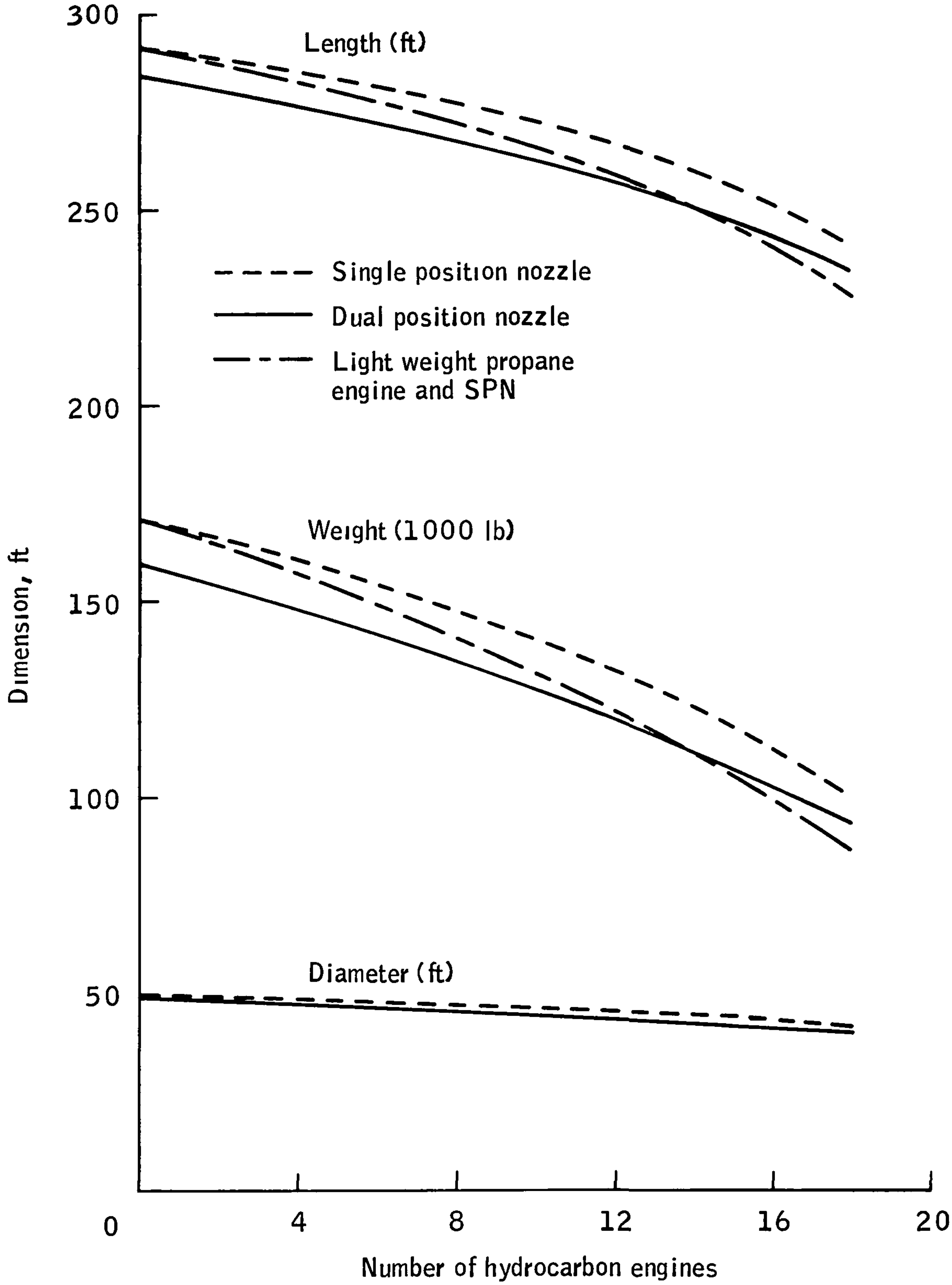

Figure VI-B-7.- External hydrogen tank characteristics.

VI BASELINE SYSTEM

The baseline modified single stage to orbit heavy lift launch vehicle has a main propulsion system with 5 hydrogen fueled dual expansion ratio engines and 16 propane fueled fixed expansion ratio engines. The vacuum thrust of each engine is 1 806 000 pounds.

The launch configuration is shown in figure VI-B-1. The orbiter and external hydrogen tank dimensions are summarized in table VI-B-9.

The launch vehicle weight summary is given in table VI-B-10.

~~The external hydrogen tank weight summary is given in table VI-B-11.~~

The launch trajectory is given in table VI-B-12.

TABLE VI-B-9

SUMMARY OF BASELINE MSSTO DIMENSIONS

ORBITER (Scale Factor 2.180)	
Length	329.9
Span (ft)	193.9
Height (ft) - Gear Up	77.5
Gear Down	103.3
Platform Area (ft^2)	30 421.3
Base Area (ft^2)	5 461.3
Wetted Area Including Base	84 180.8
Mold Line Volume (ft^3)	914 243.0
EXTERNAL HYDROGEN TANK (Scale Factor 1.544)	
Length (ft)	242.6
Diameter (ft)	41.6
Volume (ft^3)	288 688.6
Ogive Surface (ft^2)	4 984.8
Barrel Surface (ft^2)	22 587.8
Dome Surface (ft^2)	2 283.8

TABLE VI-B-10

BASELINE MSSTO WEIGHT SUMMARY (POUNDS)

Tail Structure	92 507
Heat Shield	158 790
Landing and Auxiliary Systems	42 254
Propulsion - Main	548 570
Thrust Structure	155 452
Orbiter Oxygen Tank	138 733
Orbiter Propane Tank	48 975
Propulsion - OMS & RCS	46 777
Electrical & Hydraulic	49 800
Surface Controls	18 864
Avionics	21 127
Cargo Compartment	36 211
Margin	130 909
Orbiter Dry Weight	1 508 969
External Hydrogen Tank	102 306
Residual & Unusable Fluids	102 306
Inflight Losses	19 184
Flight Performance Reserve	32 871
Propellant OMS	231 323
Propellant RCS	24 145
Payload	1 000 000
Propane Fuel	3 565 373
Oxygen	19 022 490
GLOW	26 795 689

TABLE VI-B-11

EXTERNAL HYDROGEN TANK WEIGHT SUMMARY (POUNDS)

TANK STRUCTURE	64 490
POLY-URETHANE FOAM INSULATION (0.75 in.)	3 659
CORK ABLATOR	14 117
ORBITER-TANK ATTACHMENT STRUCTURE	8 184
PROPULSION SYSTEM	1 625
CONTINGENCY 10%	10 231
TOTAL	102 306

TABLE IV-B-12

ASCENT TRAJECTORY AND WEIGHT SUMMARY

$INPUT GAMI=89.13,NEAI=0,NEBI=5,NECI=16,SEE=1.8056,TWO=1.3 $END

TIME (SEC)	ALT (FT)	VEL (FT/SEC)	Q (LB/FT2)	GAMA (DEG)	TANG (DEG)	WEIGHT (LBS)	TWR	NE	FN (LBS)	ALP (DEG)
.0	0.	0.	0.	90.0	90.0	26709213.	1.300	21	0.	.0
10.0	496.	101.	12.	90.0	90.0	25774295.	1.353	21	-424.	-.0
20.0	2084.	219.	54.	88.1	88.1	24759378.	1.416	21	0.	.0
30.0	4931.	355.	130.	84.7	84.7	23744460.	1.488	21	0.	.0
40.0	9214.	514.	238.	79.3	79.3	22729543.	1.572	21	0.	.0
50.0	15089.	705.	370.	72.3	72.3	21714625.	1.666	21	0.	.0
60.0	22665.	935.	506.	64.4	64.4	20699708.	1.770	21	0.	.0
70.0	31916.	1206.	603.	56.3	56.3	19684790.	1.883	21	0.	.0
80.0	42660.	1531.	606.	48.3	48.3	18669873.	2.004	21	0.	.0
90.0	54738.	1933.	542.	41.0	41.0	17654955.	2.132	21	0.	.0
100.0	67961.	2417.	449.	34.6	34.6	16640038.	2.270	21	0.	.0
110.0	82090.	2984.	345.	29.0	29.0	15625120.	2.422	21	0.	.0
120.0	96870.	3613.	251.	24.3	24.3	14634838.	2.465	20	0.	.0
123.0	101291.	3809.	227.	23.0	23.0	14347419.	2.417	19	0.	.0
CHANGE TO INERTIAL										
123.0	101291.	5254.	227.	16.5	23.6	14347419.	2.417	19	68992.	.5
130.0	111730.	5733.	173.	15.1	23.2	13714658.	2.399	18	271068.	2.8
140.0	126599.	6421.	116.	13.3	21.6	12869359.	2.418	17	255947.	4.1
150.0	141350.	7121.	79.	11.9	20.5	12077633.	2.427	16	219568.	5.4
175.0	177238.	8906.	34.	9.0	17.7	10322156.	2.491	14	117713.	6.8
200.0	210994.	10714.	15.	7.0	15.5	8852120.	2.497	12	56517.	7.4
225.0	241934.	12526.	6.	5.4	13.8	7627108.	2.424	10	24345.	7.7
250.0	269534.	14370.	2.	4.1	12.7	6586496.	2.259	8	9023.	8.1
275.0	293457.	16195.	1.	3.1	10.3	5725856.	2.283	7	2577.	6.8
300.0	313621.	18028.	0.	2.3	8.1	4999096.	2.254	6	820.	5.5
325.0	330125.	19794.	0.	1.7	8.2	4406205.	1.718	4	469.	6.3
350.0	343348.	21225	0.	1.3	4.8	3993025.	1.896	4	150.	3.4
375.0	353545.	22826.	0.	.9	2.0	3579845.	2.114	4	33.	1.0
400.0	361097.	24632.	0.	.6	-.3	3163664.	2.390	4	-23.	-.9
414.5	364535.	25665.	0.	.5	-2.0	2951605.	1.923	3	-60.	-2.5

VC 28800. APOGEE ALT 485599. PERIGEE ALT 84779.
DV1 412. APOGEE ALT 1640326. PERIGEE ALT 336260.
DV2 375. CIRC ORBIT 270 NMI DEORBIT VELOCITY 440.

MSSTO LAUNCH VEHICLE WEIGHT STATEMENT (LBS)

SF 2.108 SFET 1.544 SFE 1.806 OPSCOST 5954593. VLAND 195.

PALOAD 999991.

TAIL STRUCTURE	92507.	ELEC&HYDRU	49800.
HEAT SHIELD	158790.	CARGO COMPARTMENT	36211.
LANDING AND AUX SYST	42254.	SURFACE CONTROLS	18864.
PROPULSION-MAIN	548570.	AVONICS	21127.
PROPULSION-OMS&RCS	46777.	MARGIN	150909.
INERT WEIGHT1508969.			
RESIDUAL&UNUSABLE FL	45045.	PROPELLANT OMS	231323.
RESERVE FLUIDS	0.	PROPELLANT RCS	24145.
INFLIGHT LOSSES	19194.	FLIGHT PERFOM RES	32871.
ORBIT HYDROGEN TANK	102306.	HYDROGEN FUEL	1243993.
RP-1 TANK	48975.	RP-1	3565373.
LOX TANK	138733.	OXYGEN	19022490.

INPUT
DUAL POSITION NOZZLE 60/270, NOZZLE EXTENDED AT 100000 FT.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

REFERENCES

1. Study of Alternate Space Shuttle Concepts, Final Report, Lockheed Missiles and Space Co., Report LMSC - A989142, ACS-124A.

2. Research Study to Identify Technology Requirements for Advanced Earth-Orbital Transportation Systems, Final Review, Martin Marietta Co., MCR-75-325 (Issue 3).

3. Technology Requirements for Advanced Earth Orbital Transportation Systems, Mid-term Briefing, Boeing Aerospace Co., D180-19168-1.

VI. SPACE TRANSPORTATION SYSTEM

B. HEAVY LIFT LAUNCH VEHCLE

VI-B-4. Launch Vehicle Cost Analysis J. Akkerman
Future Programs Office

The costs for payload delivery to low Earth orbit can be divided into four categories.

1. Booster
2. Propellant
3. Operations
4. Facilities

Each of these categories is discussed in detail below and the totals are summarized in Table VI-B-13.

Booster Costs: Vehicle costs have been estimated by several groups in recent months. The results have been similar with about a factor of two (between 3 and 6 dollars per pound of payload delivered to low-Earth orbit including spares). One of the estimates, made by Boeing, was on the order of $3 and was based upon a grass roots investigation. The contractor considers the number conservative as it includes the cost of facilities, tooling, profit and all the other items they include in estimating any commercial venture in aircraft production. Of all the studies done to date, this one has by far the most credibility. The only factor to keep in mind is that the cost is based upon conventional contemporary design, overlooking many potential cost reduction concepts.

The 6 dollar estimate was made by extrapolation of in-house historical cost models for hardware and maintenance. As mentioned above, most of the experience to date has been with programs which put most emphasis on minimizing the cost of development, with little consideration of hardware production costs or operations costs. As a result, the models are understandably very likely to be high, especially on the maintenance/repair factors. Most of the hardware we have dealt with in the past has been for one time only use. In many cases the items were "worn out" by excessive testing before they were flown. The HLLV hardware designs will very likely show a much better track record in this respect.

A third approach to reflect reasonable costs tended to validate the contractor data. This costing approach involved the use of "unit cost per pound" as reflected by similar hardware items. By plotting the mass fraction of various rocket systems as a function of size, as shown on Figure VI-B-8, the dry hardware weight of the HLLV can be established to a reasonable degree of certainty. Note that the lower large stages are more efficient from a mass fraction standpoint, indicating that as we go

to larger vehicles, we can expect better mass fractions. The EDIN 338-76 vehicle used as a cost base design is shown at the top of the graph at a relatively low mass fraction, especially considering the size of the two stages. This results because of two reasons: (1) a relatively conservative design including reserve factors, and (2) it is a reusable, winged vehicle which may indeed involve more hardware.

Using the EDIN hardware weight, which should represent the upper limit for HLLV type boosters, Figure VI-B-9 can be used to estimate the cost of the vehicle. Note the consistency of costs for various types of vehicles. Road vehicles consistently cost very near to $2 per pound, whether they are cars, trucks, or trains. Light planes with piston engines all cost between $10 and $20 per pound, business jets between $130 and $180 per pound. Probably the most significant group is the heavy aircraft transports. These vehicles are almost as large as the HLLV. They fall into a range of $120 to $200 per pound, an amazingly narrow band considering the variations in design; number of engines, navigation gear, range capability, payload, etc.

All this lends confidence to choosing a number for cost per pound for large rockets although we have not built very many large rockets. The only really good data point is the SIC at $200/pound; the first stage of the Saturn rocket which flew the Apollo missions. This is indeed a mammoth vehicle in terms of rocket experience. It was built with five engines of about the size required for the HLLV. Only twenty units were produced. The dollar cost reflects the cost of tooling, development, etc. By all standards, this should be a conservative example of dollar cost per pound; especially considering that the HLLV will amortize its development and tooling costs over a production run of hundreds of vehicles.

The Shuttle number is nearing reality and even with some growth in the final stages of development, it should fall into the $200 to $300 per pound range. The contractor estimates for the HLLV as discussed above fall at about $200 per pound and with a lifetime worth of spares it comes up to about $300/pound.

The only notable exceptions on Figure VI-B-9 are some of the recent high performance military aircraft, B1, F111, F15. The vehicles are very special and push a large frontier of technology in engines, guidance and controls, weapons, aerodynamics and many others. The HLLV is a simple extension of well established technology. No new guidance is required, no different aerodynamic environments are involved; now new things are involved in engines or structures. The HLLV lift-off weight will simply be about four times that of the Saturn, and it will put about four times as much payload into orbit.

Thus, the costs to be expected for the HLLV can be somewhat confidently predicted to be somewhere in the $200 per pound range,

based upon existing experience, technology and designs. As outlined in the Booster Cost Breakdown sheet, Table VI-B-14, this price (assuming 50% replacement in each 5-year - 300 flights - period) is \$2.39 per pound to LEO. This represents a conservative estimate. A nominal cost would be about 90% of this number (\$2.15/pound to LEO) and perhaps an optimistic (but probably achievable) number would be 80% of this number (\$1.91/pound to LEO).

Development cost for the booster is assumed to be four equivalent vehicles, two of which are refurbished and used in this flight program. The development cost is then amortized over the flights in 10 years and results in a cost of less than 10¢ per pound delivered to LEO.

Propellant Costs: The costs reflected in Table VI-B-15 are based upon propellant loading requirements established for the EDIN 338-76 booster (a conservatively sized unit as discussed above) plus 10% for spillage. The prices are those described in Section D for propellant costs. These numbers are very much in line with all estimates that have been made to date. (See the Propellant Cost Breakdown in Section D.) These prices are for commodities produced from coal by the Lergy process. This process tends to make hydrocarbons on the light end, particularly methane. This makes hydrogen particularly cheap, and propane unproportionately expensive. Even though the individual costs of fluids are very different from what is typical of fluids produced in a normal petroleum industry (like today's), the total costs per flight are about the same. It is expected that a rocket using methane entirely will show a marked decrease in propellant cost, perhaps to a little as half the number shown. (See the Section VI-B-5 on HLLV cost effectiveness designs.)

Operations Cost: By far the most abstract item in the HLLV cost picture is the operations cost. There has never been an activity that is comparable. The costs of wartime efforts are far too diversified to be applicable. Airline operations approach the magnitude involved, but direct application of airline data produces costs so low as to be hardly believable (5¢/pound to LEO). The Shuttle operation is somewhat akin to that planned for the HLLV, but is not in practice as yet. There is a great temptation to simply use planned Shuttle operations cost per flight data to estimate HLLV costs. There are hazards in this, however, in two areas: (1) flight rates, 1 per 6 days for Shuttle, 6 per day on HLLV, and (2) Shuttle funding for operations is directed to include all personnel from all sectors to what ever extent they are involved. This results from the management directive that all NASA budgets be "program based."

It would be a financial catastrophy to operate the HLLV as an entirely government activity in the same sense as the initial Shuttle flights are planned. In any event, the "scale-up" factor of 36 times as many flights would certainly allow some considerable reduction in government "monitoring" activity on a per flight basis.

The present Shuttle operations cost is expected to be about $9.5 million per flight. This is shown in Table VI-B-16, Operations Cost. If the government costs in all areas except the launch facility are assumed to be constant beyond the Shuttle program and into the SPS program, and if the Shuttle projected costs per flight are used for the launch facility operations only, including vehicle repair, stage retrieval, etc. the result is $5.46/pound to LEO as shown in Table VI-B-16. This should represent an early phase cost to which some degree of learning would result in a reduction. The HLLV operation should not be nearly so complex on a per flight bases as the Shuttle, since the payload is essentially the same in all cases. There should be little attention required for the SPS parts as compared to the items normally delivered by Shuttle. The profusion of flights (6 per day) would certainly motivate a streamlining of operations over a period of time. The dollars involved would certainly fund automation in reviewing flight data, servicing operations, stage retrieval, checkout and even in repair. It is reasonable that these costs could be reduced by 20 percent as a nominal (4.33), and possibly 40 percent to represent an objective minimum (3.25).

These numbers are extracted from a current program, concentrating on reducing front end costs (DDT&E) and paying relatively little attention to design alternatives which cost a little more in development but would greatly reduce operating cost in the future. This financial environment of minimizing front end costs altered the initial all up reusable Shuttle design concept (which had payload costs to LEO for about $20/pound) to what we have now ($300/pound to LEO). Any program to support the HLLV must be planned with the benefits of operationally cost effective designs in mind and must willingly support the costs of the development required.

Facilities/DDT&E: Original plans to estimate costs of HLLV put primary emphasis on defining early funding costs for facilities and development. However, in every case, these items have been found to be negligible considering the other costs. As an example, for facilities, if the land based vehicle (EDIN 338-76) is flown from a southwest United States area (Chinati Peak, Texas) as outlined by the WSTF study documented in Section VI-B-6, and the costs are amortized over 10 years of the program, the result is about 18¢ per pound in LEO. A portion of the costs are somewhat fixed, while some are used on a per flight basis. For example, the administration building will be essentially the same no matter how many flights are involved. This along with the tow path, the land, etc., if amortized over the total flights in 10 years (21,900 flights) amounts to about $.095 per pound into LEO. The other facility items (the ones more directly associated with launch rate), pads, tractors, etc. add up to about $.06/pound to LEO. These numbers are practically insignificant compared to other costs ($.16 out of $10 = 1.6%) means that we can spend about $61.50 on improved facilities to save one dollar per pound launched into Earth orbit, i.e., booster operation/production/propellant, etc. This practically quarantees efficiency in the latter areas with little extra cost. These numbers are shown in the calculations described in Table VI-B-17.

Total Costs: The HLLV costs outlined in Table VI-B- 13, 10.89 high, 8.44, nominal 6.0 low, represent achievable levels using the existing technology. The spread is representative of that to be expected in any such new program.

With development of new booster designs (using today's technology, but emphasizing cost effectiveness instead of minimizing DDT&E) these costs can be expected to reduce substantially. Section VI-B-5 on HLLV cost effectiveness design considerations discusses this in some detail.

TABLE VI-B- 13

HLLV Costs
(Dollars/Pound--LEO)

	Booster	Propellant	Operations	Facility Recurring	*Nonrecurring (Amortized) Booster DDT&E	Facility	Total
Hi	2.39	2.57	5.46	.12	.20	.19	10.89
Nom	2.15	1.58	4.33	.09	.15	.14	8.44
Min	1.91	1.59	3.25	.06	.10	.09	6.00

*For six flights per day on 10 year program = 21,900 flights

Booster

$\frac{4.31B}{21{,}900 \text{ flts}}$ = \$196,803.65/flt

$\frac{3.23B}{21{,}900 \text{ flts}}$ = \$147,488.58/flt

$\frac{2.157B}{21{,}900 \text{ flts}}$ = \$98,493.15/flt

Facility

$\frac{4.190B}{21{,}900 \text{ flts}}$ = \$191,324.20/flt

$\frac{3.14B}{21{,}900 \text{ flts}}$ = \$143,378.99/flt

$\frac{2.095B}{21{,}900 \text{ flts}}$ = \$95,662.10/flt

TABLE VI-B-14

Booster Cost Breakdown
(Dollars per Pound to LEO)

Five years reuse w/300 flt, i.e., 1 flt/6 days

$$\frac{5 \text{ years} \times 365 \text{ days/yr}}{300} = \underline{6.08 \text{ Days Turnaround}}$$

Assume the booster is 50% replaced during its lifetime -
i.e., $200/lb X 1.5 = $300/lb total useful life cost.

Weight Breakdown (EDIN 338-76)

21,331,885 lbs gross weight

Lift off wt.	21,095,563	
Booster Stg wt.	14,094,797	
Propellant	12,557,911	
	1,536,886	lbs first stage dry wt.
Interstage	+ 59,313	
	1,596,199	
Second stage inert	+ 736,425	
dry wt. contg.	+ 64,758	
	2,397,382	lbs total dry wt.
	X 300.00/lb	(including 50% replacement during 5 yr life)
	$719,214,600	/300 flights

= $2,397,382/flight for 5 years use (with spares in)

DDT&E = 2 X CFU + 2 (.5) (CFU) = 3 X CFU
3(719,214,600) = 2.157 Billion

$$\frac{2.157\text{B}}{21{,}900 \text{ flts/10 years}} = \$98{,}493.15/\text{flt}$$

For 1,000,000 pound payload, this results in $.098493/lb to LEO (10¢)

TABLE VI-B-15

Propellant Cost Breakdown
(Cost per Flight)

EDIN EX 338-76

STAGE I

Oxygen	9,438,991
Propane	3,517,454

STAGE II

Oxygen	4,421,258
Hydrogen	748,451

BEST

5%	Propane	.08/1b	Stage I	Oxygen	151,023.85
	Oxygen	.016/1b		Propane	281,396.32
	Hydrogen	.05/1b			
			Stage II	Oxygen	70,740
				Hydrogen	37,422.55
					540,582.85 X 1.1 =
					$ 594,640.20

N

7-1/2%	Propane	.25	Stage I	Oxygen	198,218.81
	Oxygen	.021		Propane	879,363.50
	Hydrogen	.36			
			Stage II	Oxygen	92,846.41
				Hydrogen	269,442.26
					1,439.871.08 X 1.1 =
					$ 1,583,858.19

WORST

10%	Propane	.42	Stage I	Oxygen	245,413.76
	Oxygen	.026		Propane	1,477,330.68
	Hydrogen	.67			
			Stage II	Oxygen	114,952.70
				Hydrogen	501,462.17
					2,339,159.32 X 1.1 =
					$ 2,573,075.25

TABLE VI-B-16

Operations Cost
(9.6 million $/flt 6 flts/day)

	Shuttle	HLLV
JSC	.704	.0195
JSC Contractor	1.107	.0307
MSFC	.381	.0105
MSFC Contractor	.041	.0011
KSC	1.287	1.287
KSC Contractor	1.380	1.380
KSC Ground Operations	2.303	2.303
OTDA	.165	.0045
HQ	.328	.0091
Program Support	1.080	.0300
Other	.115	.0031
SSME Ohaul	.368	.368
Sys	.016	.016
Crew GSE	.269	no flt crew
	9.543	5.462

TABLE VI-B-17

Facilities Cost
Chinati Peak, TX
(See Sec. VI-B-5)

NONRECURRING

Tow-way Costs - \$1.65M/mi. X 253.1 mi. (pp 21 & 13, respectively) (6 Lane Divided Highway)	\$ 414.64M
Range Control	90.0 M
Utilities on Tow Path & Launch Area	30.0 M
Parking Pad	1.0 M
Land Costs (pg 13)	1,490.0 M
Landing Area	70.0 M
	\$2,095.64M

$$\frac{\$2{,}095.64M}{21{,}900 \text{ flts}/10 \text{ yrs}} = \$95{,}691/\text{flt}$$

RECURRING

Pad:	Lasts 10 yrs, one flight/day - (May continue to be used, but refurbishment costs = cost of new one past 10 yrs.	
	i.e., 3,650 flts/pad	
	Cost new = \$120M/3650 flts =	\$32,876.00/flt
Industrial Area:	(6 bays/6 veh (1 flt/day)) 40M/3650 flts =	\$10,958.90/flt
Admin. Building:	5M/3650 flts =	\$1,369.86/flt
GSE:	(Equal to 1 booster but services 6 - same life)	\$398,000.00/flt
Payload Building:	(10 Yr) (20M/3650 flts) =	\$5,479.00/flt
Tractors:	For return (3M ea.) (3 required)	
	5 year life $\frac{9M}{(5)(365)}$ = 4931.50/flt + 100% for fuel maintenace & service =	\$9,862.00/flt
	TOTAL	\$60,545.76/flt

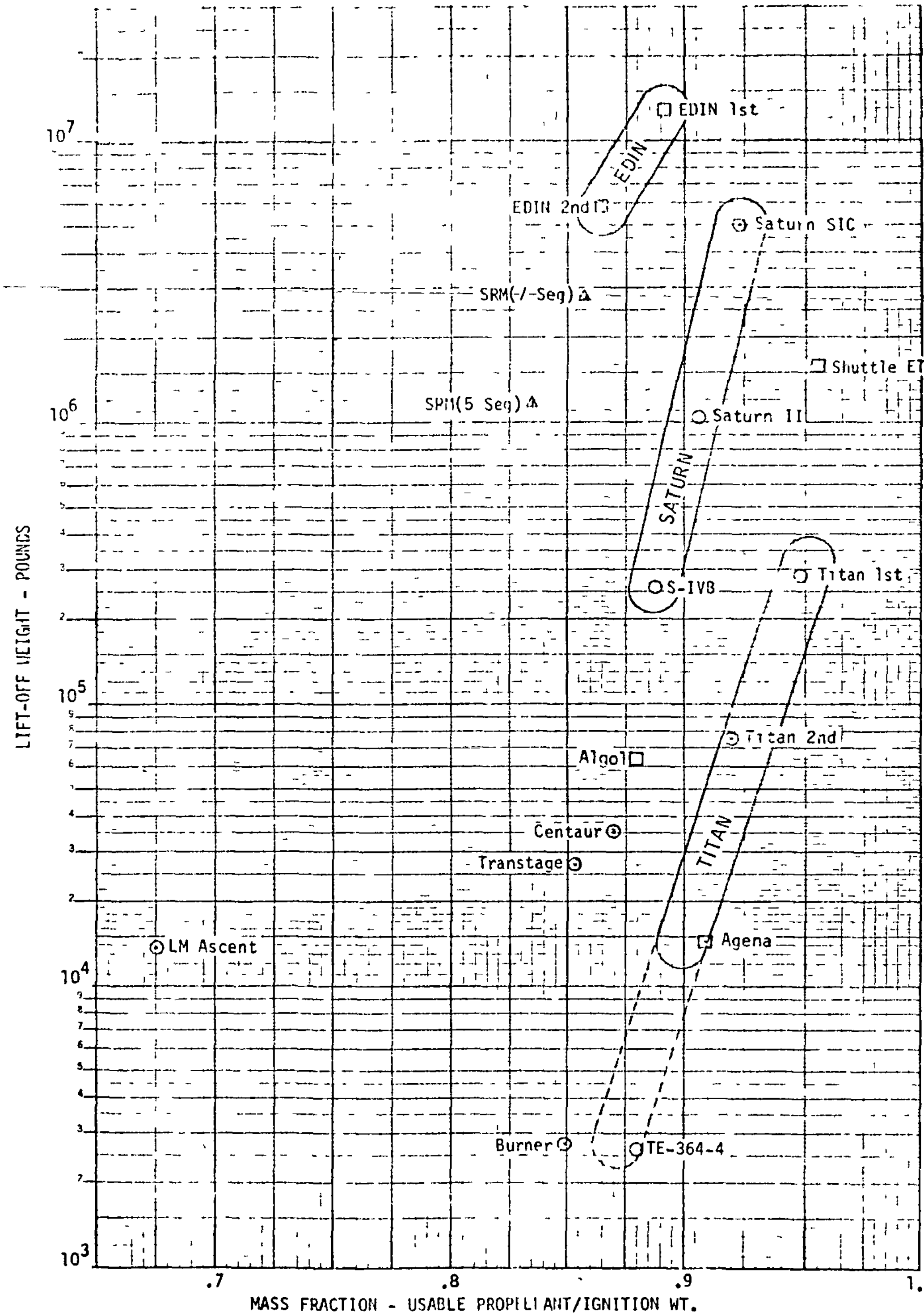

Figure VI-B-8. Vehicle Lift-off Weight VS. Vehicle Mass Fraction

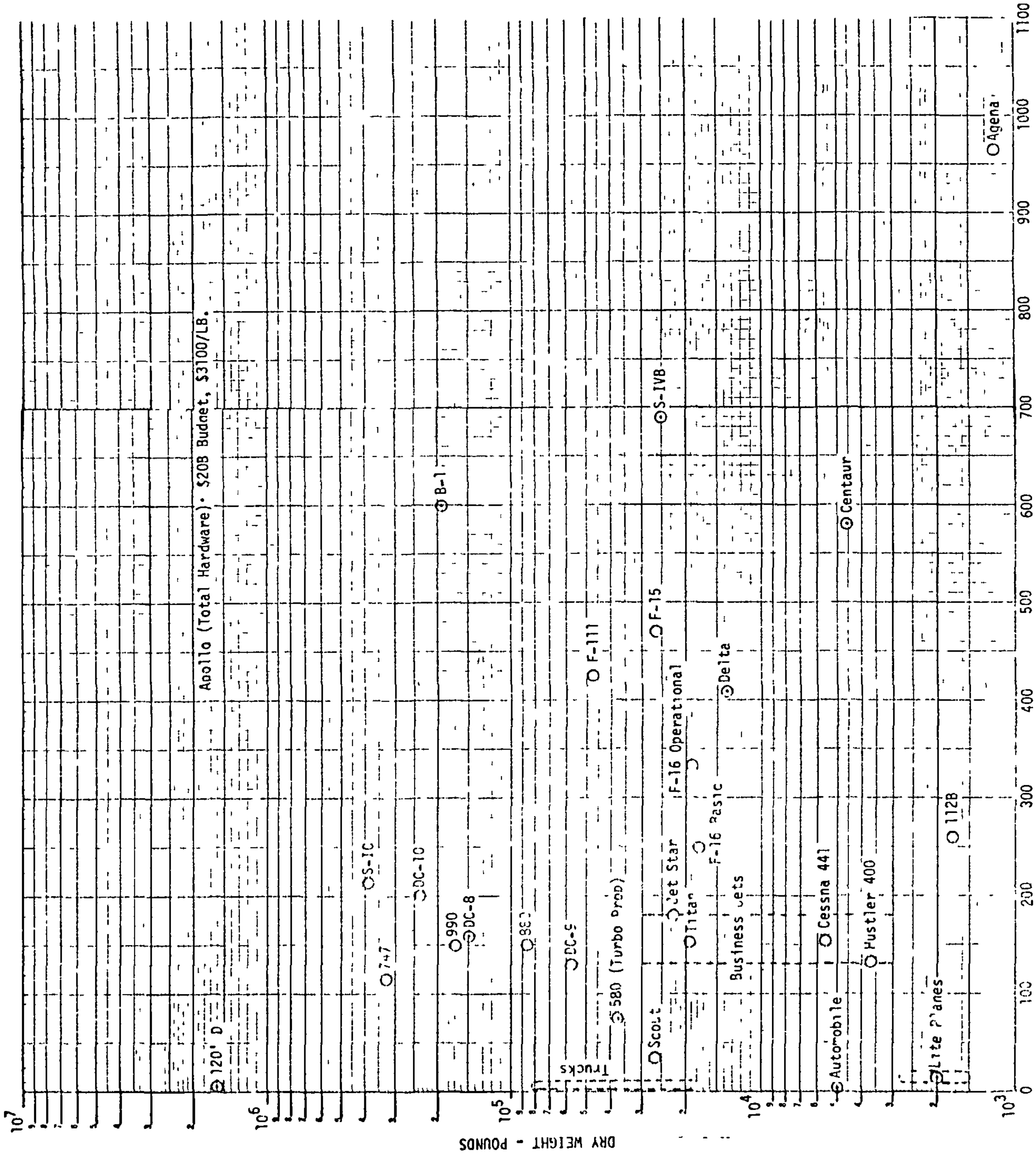

Figure VI-B-9. Hardware Dry Weight VS. Hardware Cost Per Pound

B. HEAVY LIFT LAUNCH VEHICLE

VI-B-5. Design Considerations

J. Akkerman
Future Programs Office

The following items will be discussed in detail below:

1. Water transportation
2. Launch site location
3. Booster reserves and conservatism
4. Development and hardware utilization
5. Hardware designs and maintainability

Water Transportation: Two factors drive the SPS program toward maximum utilization of water transportation.

1. Cost per ton mile
2. Size of the items involved

The existence of world trade is documentary to the low cost of water transportation. Land transportation--even the largest scale imaginable--the railroads--is prohibitively costly on anything but finished goods. The high prices paid for common items like gasoline in areas remote from gasoline production are documentary to high land transportation costs. Delivery of a Japanese car to the U. S. is less in many cases than subsequent delivery a few hundred miles inland.

The second item--the size of the SPS items involved--is also a major factor to consider. Probably the largest single item ever transported across land is the Apollo stack. It weighed about 1,000,000 pounds--about the weight of a 20 car freight train. This was a small load by comparison to the first stage of the HLLV. Present concepts of the second stage are almost as big and heavy. Transporting these items several hundred miles on land represents a significant challenge.

On the other hand, water transportation of such large items is a daily occurrence in the ocean ports of the world. The total weight of the finished SPS is hardly as much as a large ship, and it will be delivered in several hundred flights of the HLLV. Indeed, the SPS items are relatively small by comparison to many things carried by water transportation.

It is very likely that any cost effective HLLV will maximize the use of water transportation.

Launch Site Location: The use of water transportation can provide a lot of flexibility in choice of launch site. However, there is one major factor over-shadowing all other considerations in this

choice--the fact that booster payload to Earth orbit is significantly increased by launch near the equator (about 20% over launches from the southern U. S.). At $10 per pound for delivery of payload to low Earth orbit, this amounts to $2,000,000 per flight for typical HLLV concepts. This differential, plus the almost unlimited launch window, makes the equatorial launch very attractive. This combines with a fundamentally water type booster operation to promote a site south of the west coast out in the Pacific Ocean. A few shallow places are available several hundred miles off the coast of South America. Such a site should be very cost effective if properly utilized. Floating, but anchor-stabilized launch facilities can be built competitively in any of the large shipyards.

Booster Reserves and Conservatism: Most booster programs have used sizable reserves to guarantee a given payload. The HLLV as an operational vehicle should avoid this inefficiency. This can be done if each booster is fully loaded but capable of unloading a portion of the payload in flight if the performance is less than expected. About half of the payload delivered to Earth orbit will be liquid for propulsion and other uses, and can easily be dumped in flight or used in the second stage propulsion. The SPS should plan on this efficiency improvement early in the design phase. Statistically, very little payload would ever be lost, providing significantly increased payload.

Development and Hardware Utilization: The development costs supporting the SPS will no doubt be a factor in the overall cost of delivered electricity because the development cost occurs on the front end, and is paid for after the program succeeds.

The key to minimizing development is to develop only those items which will be used throughout the program, i.e., to develop building blocks or modules upon which the total operational concept can be constructed. This improves reliability also since a lot of operating experience is gained with each element. The Shuttle is a good basic step in that direction. Any cost effective program will utilize the Shuttle vehicle to its fullest capability. There is no doubt that it can be used for guidance or flight control system development. Also, its down payload capacity can likely be utilized to recoup the valuable part of the second stage of the booster, i.e., the engines. The tank for the second stage will not be retrieved on a cost effective basis as discussed below. About half the payload for the HLLV can be carried in the Shuttle payload bay, and about half in a tank mounted between the Shuttle and the booster tank or in the second stage tank. The engines for the second stage must (in this case) be small enough to fit into the Shuttle cargo bay. Engines of the spike nozzle type are small enough, light enough, and yet will deliver the necessary 6 to 9 million pounds thrust.

Actually, the second stage of the ultimate HLLV vehicle, can be used as a booster to replace the SRB for the Shuttle. The thrust and

weight are about the same for both applications. Figure VI-B-10 shows two boosters--the smaller is a shuttle derivative and the larger a possible HLLV. In the early phases, the Shuttle would fly with its external tank and the main propulsion system/OMS, etc. all in place. The first stage--the liquid rocket replacement of the solid units--would be retrieved ballistically like the SRB and as ultimately would be the case for the HLLV first stage. A lot of valuable experience can be gained with this hardware during the early parts of the program. When the need for the all-up HLLV finally matures, the external tank and main engines would be removed from the Shuttle and the old first stage would become a second stage. A new first stage would then be added. The new large first stage (28 to 32 million pound thrust) would be ballistically retrieved with a water landing and shipboard return. The second stage engines would be returned via the Shuttle, leaving the tank in orbit. The Shuttle would land in the vicinity of the payload production facility, or at least near the site where the payload is assembled, near a sea port. The second stage would very likely be stacked during the voyage to the launch site. The engines would be removed from the Shuttle payload bay and placed for assembly. The new second stage tank would be stacked over the engines. The tank for the expendable part of the payload (returned with the Shuttle in the area where the main engines are located presently) and the Orbiter would then be stacked into place. About half the payload for the HLLV would then be placed into the cargo bay of the Orbiter (SPS structure, solar cells, etc.). The entire dry second stage stack would weight just about 1,000,000 pounds. The necessary control wires, etc. for the engines would be connected and the entire assembly would be ready for stacking onto the first stage. After connecting still more control wires from the orbiter to the first stage and servicing, the system would be ready to fly. Possibly,the propellant part of the payload would be carried in the second stage tank.

This hardware evolution would require the development of two new engines and two new stage tanks to complete the HLLV. The first engines would be about 13 feet in diameter, about 7 feet long and would produce about 2 million pounds thrust running on hydrogen and oxygen. It should be of the spike nozzle type for the sake of size and also to accommodate early use as a low altitude engine and later use as an upper stage engine. An appropriate compromise must be reached for the selection of the spike configuration. Five of these engines would power the vehicle. The second engine would very likely be a segmented aero-spike type--16 of which would power the HLLV first stage. It would likewise have a thrust in the range of 2 million pounds and would use the very similar pumping machinery as the first engine but would run on methane. The only really new part would be the liquid cooled segment to fit under the stage.

The first of the two new stage tanks would be a unit to hold about 5 million pounds of propellants. It would be about 42 feet in diameter and about 200 feet long. It would have a simple interface for easy attachment

of the engines on one end, and the payload/orbiter on the other. It should have a tunnel through the center for connection of the necessary control wires for the engines. Simple clamps would be used to connect the engines and the plumbing.

The second tank to be developed would be very similar to the first, but would hold about 16 million pounds of propellant. It would be about the same diameter as the upper stage (46 feet), and would stand almost as tall--150 to 200 feet.

Steering for the stages would be provided by differential throttling of main engines, with roll control being provided by the orbiter systems. (Very little roll control would be required in an equatorial launch since there would be virtually no propellant vortexing. The two new stages would be simple mechanically compared to today's rockets. Gimbals and the necessary power systems to drive actuators would be eliminated. The opening at the base of the spike nozzle (which would be used in flight to dump the turbopump exhaust) could be closed during sea landing to keep the machinery dry. Some mechanical device might also be devised to plug the nozzle throat also to keep the inside of the pumping machinery and the injectors dry.

Beyond the normal Shuttle type operation, the only new operation would be the ballistic recovery of water-landed first stages. This would not be greatly different from the recovery of the solid rocket motors presently scheduled in the Shuttle operation of water recovery of the liquid booster for the interim vehicle. The major difference would be in size of the elements involved. The operational plan would evolve from SRB's to the 9M thrust booster (future second stage) to the 32M thrust all-up HLLV first stage.

Hardware Designs and Maintainability: Every effort should be made to keep the entire hardware program simple enough for every one involved to fully understand. The elimination of the gimbal system is a great stride in that direction. Modularization of hardware elements and commonality between the first and second stage engine pumping hardware should greatly reduce maintenance operations. These innovations and design features will no doubt impose upon engine performance and the ultimate in optimized specific impulse, but the money saved will easily pay for any extra propellant required.

The use of the expended upper stage tank should receive careful consideration, especially for use as a one-way OTV. It is not worth recovering out of Earth orbit even if it is not used effectively in LEO. However, something must be done with it. The construction of one SPS will leave 500 to 700 of these tanks in LEO and that amounts to about 18 to 26 miles of tank in orbit. These units will have walls about 3/16 to 5/16 inch thick and a pressure capability on the order of 30 to 50 psi. They could be used to form the columns of a cable/column design SPS. Also, all

the propellant necessary for the GEO trip could be stored in these tanks. The tanks in this case might be specially insulated to minimize reliquefication energy requirements. In any case, the tanks will be excess baggage unless something can be planned for their use. One set of second stage engines can provide the GEO transfer in 4 to 20 hours depending on how many are burned at one time and the final SPS weight.

The fact that the second stage tanks are not worth retrieving is based upon the assumption that the production costs at the required production rate (six tanks per day typically) will allow production at a cost of about twice the material cost. This is typical for high production items like automobiles, hamburgers, etc. Since the tank weighs about 80,000 pounds and the aluminum costs about $1.00 per pound, the tank will cost about $160,000 each. The cost to get it into orbit is about $800,000 ($10/pound). If this tank is deorbited along with the engines, the Shuttle can be left off, but the assembly would then need wings, wheels, thermal protection and grow to something akin to a Shuttle orbiter only larger much like EDIN 338. Assuming the down payload is about 50% of the retro weight, a 160,000 pound unit would have to be put into orbit; an extra 80,000 pounds (or $800,000 worth). This would have to be deorbited at a cost of about 8,000 pounds of propellant (Isp = 400--delta V = 500 ft/sec). This costs about $80,000 at $10/pound. These numbers make the cost of a new tank look attractive by any standards whether the tank is used in orbit or not.

The same logic applied to engines shows a marginal cost effectiveness, but since the cargo bay of the orbiter will be returning empty anyway, the engines actually can come home free. The orbiter serves as a cargo shroud and guidance on the way up as a primary function (rather inefficiently of course) but since it can serve the function of engine return, its inefficiency is somewhat alleviated. The system will likely prove to be most cost effective when flown manned anyway as the crew can do the docking, unloading, loading, retro and landing operations with simpler systems than automatic systems might. The reliability required for man rating will be inherent in the design because of the high cost of losing a vehicle. Also, as discussed in costs, the DDT&E for the vehicle is insignificant.

Although the details will no doubt change the mode of utilization of the above cost effectiveness items, they should prove to be sound baseline objectives for each new concept considered. To summarize, several areas of detail study for cost effectiveness that need to be considered are:

a. Booster design emphasizing evolution of Shuttle to HLLV with minimum new hardware.

b. Water landing system design for the first stage and water transportation back to the pad.

c. Crane and/or hoist design for water operations (possibly a floating unit).

d. Launch pad designs.

e. Propellant supply system optimization all the way from source to loading.

f. Payload/second stage transportation and operations details.

g. Possibility of using the second stage tank for SPS structure and/or orbit transfer fuel storage. (Possibly a one way OTV using second stage HLLV engines.)

h. Spike type engine/pump details with simplified controls and fast throttle response.

i. Payload dumping parametric studies and/or payload in second stage tanks.

j. Booster steering with differential throttling.

k. Booster tank pressurization systems parametric studies.

l. Overall booster/propellant design trade-off studies for cost effectiveness emphasizing the results of e.

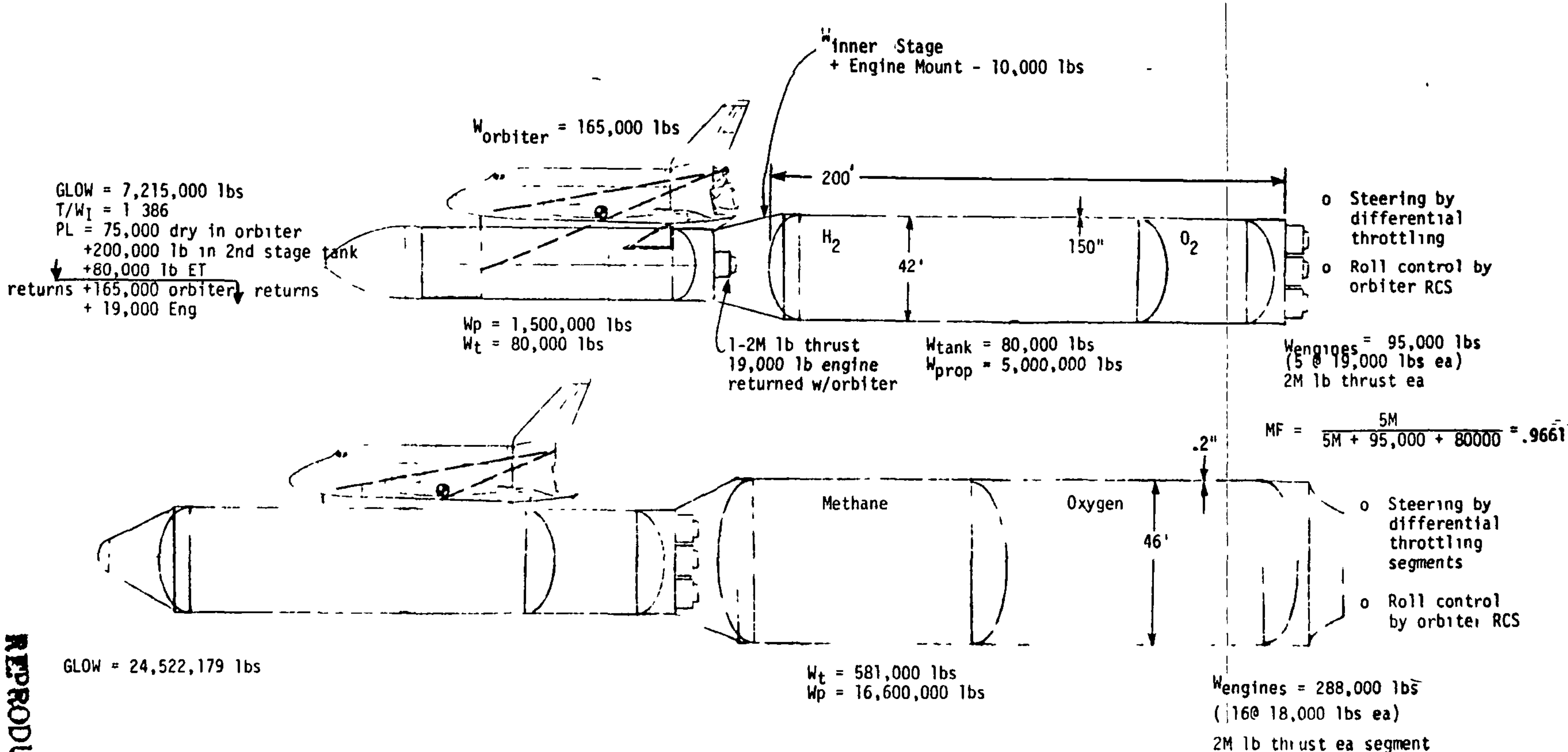

Figure VI-B-10. Possible Shuttle Growth and HLLV Configurations

VI. SPACE TRANSPORTATION SYSTEM

B. HEAVY LIFT LAUNCH VEHICLE

VI-B-6. Western U. S. Launch Sites for the Heavy Lift Launch Vehicle

Robert Munson
White Sands Test Facility

White Sands Test Facility personnel examined the feasibility of launching the two stage winged launch vehicle described in Section VI-B-2 from the southwestern United States at launch rates required by the SPS. Six typical launch sites were examined and cost drivers for future site selection and design were identified. Preliminary cost estimates of launch site construction and operations were made to test some of the site selection criteria. The complete report is included as Appendix VI-APP-B.

The advantages of a western U. S. launch site include weather, since there are no hurricanes or large scale tropical storms, and a minimum corrosion problem. The savings in corrosion related maintenance over seacoast sites were estimated to be 80 to 90% for facilities and ground equipment and the savings in corrosion control requirements for the launch vehicle were estimated to be on the order of 1 to 2% of the vehicle weight for equivalent vehicle lifetimes. Disadvantages with respect to equatorial launch sites include restricted launch windows and a payload penalty of approximately 7.3 metric tons or 16,000 lbs because of the latitude.

Seven launch site areas were selected for study. One was eliminated early because of high population density and other reasons. One of the remaining six, located near Animus, New Mexico, was selected to examine cost and design details. The launch and recovery zone is a key shaped area, approximately 200 miles long and includes a debris corridor. It is diagrammed in Figure 1 of VI-APP-B. The tow back road or track is not restricted to the zone limits.

The report indicates that launch sites located in the southwestern U. S. could support the two stage winged launch vehicle at SPS launch rates and that they offer some advantages over coastal, oceanic or foreign sites. No specific site recommendation was made, however, because of sensitivity to changes in vehicle design, launch-to-landing site distance requirements, and launch azimuth optimization.

VI. SPACE TRANSPORTATION SYSTEM

C. ORBIT TRANSFER SYSTEMS

VI-C-1. Orbital Propellant Handling for OTV

C. M. Jones
Future Programs Office

For the SPS space transportation scenario, all OTV's are based at LEO for fueling and flight vehicle turnaround activities. It was assumed that all OTV propellants are delivered by HLLV to a LEO depot "tank farm" or staging base for propellant storage before OTV fueling. There will be pre-flight propellant losses associated with this storage/ transfer activity in terms of daily boiloff, transfer residuals, and chilldown losses. In the FY 76 study these LEO propellant losses were estimated at 30% such that for every kilogram of OTV propellant required at LEO, 1.3 kilograms must be delivered to LEO by the HLLV. In the case of the POTV, the crew rotation mission requires that the second stage be refueled at GEO. This total GEO propellant loss was estimated in FY 76 at 50% such that for every kilogram of propellant required at GEO for the POTV second stage refueling. 1.5 kilograms must be delivered to LEO by the HLLV, and subsequently, the COTV must deliver 1.2 kilograms to the GEO depot tank farm.

A funded study was awarded in April 1977 to General Dynamics - Convair Division to expand the data base in the area of orbital propellant handling. The primary objective of the 10 month study, titled "Orbital Propellant Handling and Storage Systems for Large Space Programs," (Contract NAS 9-15305), is to conduct a system analysis and comparative evaluation to establish requirements and conceptually define candidate methods for orbital propellant delivery, transfer, storage, and operations to support large space programs, in particular the SPS, contemplated for 1985-2010.

In a preliminary exercise of the study task flow, the contractor has developed working layouts of delivery and storage tanks for "first cut" estimating of OTV orbital propellant handling losses associated with two SPS scenarios, LEO assembly and GEO assembly. The difference in the two scenarios for orbital propellant handling is the addition of the task of handling argon (LEO assembly) to that of handling LO_2/LH_2 and the long flight time (180 days) associated with the $COTV_L$. Propellant loss mass percentages for various mission phases were provided by the contractor in the First Monthly Progress Report of NAS 9-15305, dated May 25, 1977. These data have been organized according to vehicle type and mission and tabulated to obtain total propellant mass loss percentages for input to the SPS space transportation scenario synthesis section of the FY 77 study (refer to Section VI.F). Total propellant loss percentage estimations include a 25% contingency to represent the level of detail in these "first cut" estimations.

The $COTV_L$ is described as an ion electric propulsion system utilizing argon combined with a LO_2/LH_2 occultation attitude control system. As an operating system, the $COTV_L$ is separated into four parts and mounted at each corner of a one-sixteenth SPS module for the low thrust, long term transfer to GEO. A description of the $COTV_L$ may be found in Section VI-C-4. The option of propellant reliquefaction was not assumed for conservatism. The "Subtotal" data were operated on with propellant mass ratios to obtain the "Bulk Mass Subtotal" line items. The total pre-flight and flight propellant loss of 7.0 represents the additional propellant mass percentage that must be delivered to LEO to derive the OTV main impulse propellant required for the LEO to GEO transfer. (See Table VI-C-1.)

The POTV is described as a common stage LO_2/LH_2 utilizing a high-thrust transfer to GEO of approximately five hours for personnel versus the low thrust transfer time of 6 months for the $COTV_L$. As an operating system, the POTV performs the crew rotation function for the SPS space transportation scenario at a rate of 75 personnel per flight. As stated previously, the second stage is refueled at GEO for the return to LEO. Total $POTV_G$ pre-flight propellant loss percentage is seen in Table VI-C-2 as 5.4% and 10.8%, respectively, for LEO fueling and GEO fueling. Total $POTV_L$ pre-flight propellant loss percentages are seen in Table VI-C-3 as 5.4% and 19.0%, respectively for LEO fueling and GEO fueling.

The $COTV_G$ is similar in system concept to the POTV but has a larger propellant loading of 621,500 pounds per common stage compared to approximately 117,000 pounds per common stage of the POTV. As an operating system, the $COTV_G$ delivers cargo to GEO for the GEO assembly of SPS and returns with no payload to LEO for stage reuse. The total pre-flight propellant loss percentage is seen in Table VI-C-4 as 6.1% for LEO fueling of the $COTV_G$.

The options of propellant reliquefaction in LEO or during the low-thrust transfer and on-orbit processing of water into LO_2/LH_2 in LEO will be traded in the course of the contractor study. Both may reduce the long term storage losses to less than 1% but would increase systems and operations complexity. Additionally, liquid transfer versus modular tank transfer will be traded in the study for losses and systems complexity. For these estimations, modular tank transfer was assumed in propellant delivery by the HLLV tanker to the LEO depot. Complete written results with several recommended logistic concepts and their system propellant losses, cost analyses, and implementation plans will be available from the contractor in final form in February 1978.

VI-C-2. Personnel Orbit Transfer Vehicle Definition

C. M. Jones
Future Programs Office

During the period of the FY77 study, the FY 76 $POTV_L$ reference configuration, monolithic common stage, was examined further along with other LO_2/LH_2 configuration options including modular common stage, and monolithic and modular single stage for comparison. A parametric stage sizing analysis was completed for the options using the ground rules of the previous study. (Refer to Section VI-E of JSC-11568.) The geosynchronous satellite maintenance sortie mission (GSMS) was baselined with a mission delta-velocity budget of 30,132 feet per second based from 150 NM circular as compared to a crew rotation/resupply mission delta velocity of 28,366 feet per second based from 270 NM circular. The primary difference in the budgets is the GSMS requirement to visit three additional GEO sites (satellites) as seen in Table VI-C-5. The mission delta velocity budget for a LEO "repeating" orbit as described by Boeing in the SPS Systems Definition Study (NAS 9-15916) is also given for comparison. Thus, a vehicle with the initial GSMS payload sizing for early program applications will accommodate a heavier payload in the round trip crew rotation mode, especially when the second stage is refueled at GEO as was baselined for the $POTV_L$.

The particular advantage of the modular options may be also seen on Figure VI-C-1 with stage propellant loadings approaching 200,000 pounds with Shuttle compatible elements as compared to approximately 130,000 pounds limit in the monolithic (integral tanks) options. Data were generated on a 150,000 pounds propellant per stage modular common stage configuration sized for the GSMS mission. Vehicle configuration and data are presented in Figure VI-C-2. If supported by Shuttle delivery and on-orbit fueling, seven baseline Shuttle flights (payload = 65,000 pounds) will be required to establish the initial mission as depicted in Figure VI-C-3. On-orbit space basing and refueling will require only six Shuttle flights.

Although modularization of stage element does "build-in" growth potential by allowing stretch of the modular tanks, the baseline requirements of the POTV in support of SPS crew rotation do not dictate the necessity for the additional performance. Therefore, the FY 76 $POTV_L$ reference configuration of monolithic LO_2/LH_2 common stage elements (Figure VI-C-4) remains unchanged for FY 77. Table VI-C-6 presents a preliminary weight statement for the POTV reference configuration. To accommodate the 75-passenger crew rotation module and two man crew control compartment (Figure VI-C-5, -6) round trip to GEO, the second stage is refueled at GEO for the return trip to the LEO staging base as baselined in the FY 76 report. For the FY 77 study, the reference configuration for the $POTV_L$ and $POTV_G$ are baselined as the same vehicle.

Synopsis of MDAC SSAS OTV Analysis

In their performance of the Space Station Systems Analysis Study (NAS 9-14958), MDAC has produced a significant body of data on

personnel OTV. (Refer to Part 2, Final Report, Volume 3 Appendixes, Bood 2 Supporting Data, Section 11 OTV Concept Definition, dated February 28, 1977.) Similar to the JSC studies, a parametric vehicle sizing analysis was performed to obtain the optimum configuration to support GEO crew operations. The goal of the MDAC OTV design was a lightweight or high mass fraction vehicle configuration. To minimize design loads, an empty OTV launch was baselined for the space-based concept. As in the JSC studies, the LO_2/LH_2 common stage configuration was selected by with the maximum propellant volumetric size that could be launched on a single Shuttle flight. The resulting stage is 56 feet in length with engine nozzles retracted and carries a propellant loading of 129,081 pounds on-orbit. The configuration is compared to the JSC FY 76 $POTV_L$ and Boeing FSTSA manned OTV configuration in Table VI-C-7. Excellent subsystem descriptions for the MDAC common stage OTV are contained in Section 4 of Part II of the referenced report.

VI-C-3. $COTV_G$ Reference Configuration Trade Analysis

C. M. Jones
Future Programs Office

A parametric vehicle sizing and cost analysis was performed to compare the advantages of utilizing the 2-1/2 stage $COTV_G$ versus common stage $COTV_G$. During the FY 76 study, the 2-1/2 stage configuration was selected as the $COTV_G$ reference configuration on the basis of lower ignition weight at LEO for a given payload as compared to single stage, 1-1/2 stage, 2 stage and common stage (refer to page VI-D-2-5 of JSC-11568). For the FY 77 analysis, the total cost per flight was considered to account for the effect of buying and launching the expendable drop tank (DT) used in each 2-1/2 stage flight mission.

The 2-1/2 stage payload delivery mission is performed similarly to the common stage except that the stage 2 outbound propellant tank is expended at GEO and only the stage 2 core returns to LEO for reuse along with the complete stage 1. The stage 2 core would be mated with a new expendable drop tank and then with stage 1 during the space based vehicle turnaround in LEO. Both complete stages of the common stage configuration are reused at LEO. Therefore, the primary advantage of the 2-1/2 stage is the lower per mission propellant mass required to deliver the additional down propellant to GEO.

Preliminary mass estimates were derived for a common stage and 2-1/2 stage each with a payload delivery to GEO of 250 tons (551,250 lbs). Table VI-C-8 presents the main propulsion delta velocity budget as associated with a payload delivery mission by the $COTV_G$. Tables VI-C-9, -10 present the mass properties of the common stage and 2-1/2 stage, respectively. The propellant penalty of the common stage is seen in comparing the respective stage propellant loadings of 1.24M lbs (common stage) and 1.18M lbs (2-1/2 stage). Ignition weights without payload in LEO for the respective vehicles are 1.35M lbs (common stage) and 1.29M lbs (2-1/2 stage).

Preliminary cost estimates of DDT&E and TFU were derived for both configurations and are presented in Tables VI-C-11, -12. Cost per flight

estimates with groundrules are presented in Tables VI-C-13, -14 for the common stage and 2-1/2 stage, respectively. A learning curve of .88 was assumed for the reusable stages and .85 for the expendable drop tank of the 2-1/2 stage. Referring to Section VI.F, 15,152 $COTV_G$ flights are required to support the construction of 46 GEO truss SPS. Resulting average costs per flight were $13.8M and $16.1M for the common stage and 2-1/2 stage, respectively.

Referring to Tables VI-C-13, -14, HLLV launch costs for the propellant for both vehicles and the DT unit cost for the 2-1/2 stage are seen as drivers in the average cost per flight. Figure VI-C-7 presents the effect of learning on the DT average unit production cost The DT unit costs range from $3.8M for the predicted .85 LC down to $1.0M for a very optimistic .75 LC. These costs are factored into the average cost per flight of the 2-1/2 stage, and the HLLV $ per pound to LEO is varied from $5/lb to $25/lb to test the sensitivity versus the common stage in Figure VI-C-8. The common stage is seen as more cost effective when compared to the 2-1/2 stage with DT LC of .85 over the range of HLLV $ per pound to LEO.

Based on the above trade analysis, the all-reusable common stage $COTV_G$ is recommended as the $COTV_G$ reference configuration. The reference $COTV_G$ combination is seen on Figure VI-C-9.

VI-C-4. <u>Cargo Orbit Transfer Vehicle - Low Earth Orbit Construction</u>

H. P. Davis
C. M. Jones
Future Programs Office

New work on the $COTV_L$ since last year was performed by the Boeing Company as a part of the SPS Systems Definition Study, Part I (NAS 9-15916). They selected the ion engine as the best-characterized of the electric propulsion thrusters for their analysis. With some consultation by Lewis Research Center and Hughes, Boeing "scaled up" the current 30 cm ion bombardment engine being developed for the Solar Electric Propulsion Stage (SEPS) to 120 cm diameter. Operating and mass characteristics were defined for this thruster based upon the size change, modest technology advancement (readiness date of 1987) and a change of propellant from mercury to argon (Figure VI-C-10).

Boeing elected to construct modules of the solar array in low Earth orbit which have a maximum array output of 1 GW. Sixteen such modules will be built in LEO and transported to GEO to comprise a 10 GW ground output SPS. They pro-rated the microwave transmitter and other elements of the 10 GWe SPS equally among these 16 modules (Figure VI-C-11). This "nominal" mass estimate for the SPS module was 5,560 tons. An additional 18% mass was considered to be added to the SPS module to provide 13% oversizing of the array to compensate for loss of output of the exposed array (22% of the total) during transit through the trapped radiation belt, to provide for electrical power distribution of the array

output to the four electric propulsion modules at 3600 volts and structural support of the COTV propulsion system at each of the four corners of the module. Utilization of 5000 seconds specific impulse of the ion engine at 65% efficiency, 22% exposure of the array and voltage of array power distribution were derived by an optimization analysis which considered array degradation due to radiation, array power loss to the plasma, I^2R losses, thruster electrical efficiency and other factors (Figures VI-C-12, -13). Thus, a trip time of 180 days and the consequent thrust level of 5600 Newtons (approx. 1250 lbf) were selected from stability and control analyses and cost considerations. Cryogenic (O_2/H_2) propulsion systems were provided to maintain attitude control during those portions of the orbit that the satellite passed through the Earth's shadow (about 18% of the total mission time).

The dry mass of the propulsion systems for the transfer and attitude control were estimated to be 950 tons (17% of module mass). One thousand five hundred thirty tons of argon propellant and 400 tons of O_2/H_2 attitude control propellants were consumed by the mission. Total start-burn mass was thus 9440 tons, or 1.70 times the mass of the SPS module.

For the purposes of this JSC report, the Boeing concept and its parameters were accepted without change for the "nominal" SPS transportation case, but the mass requirements were normalized to the JSC "nominal" 10 GWe SPS mass estimated at 78,000 metric tons. This resulted in the following SPS module mass at start of the transfer mission.

Basic SPS module mass	4875 tons
13% oversizing for array degradation	634 tons
5% "scar" weight for the EPDS, etc.	244 tons
17% propulsive system mass	829 tons
27.5% argon propellant	1291 tons
7% O_2/H_2 ACS propellant	341 tons
OBF = 1.69 start burn mass	8214 tons

Cost per flight, "normalized" from Boeing, is \$88M, including SPS resize costs.

To define the "best case" $COTV_L$, these data were modified to capitalize upon a more optimistic set of possibilities. Foremost among the possibilities is that SPS module solar arrays may avoid any degradation during transit either by removal of the "Van Allen" belt as proposed by Dr. Owen Garriott, by the use of radiation-resistant array materials,

or by restoration of output after delivery to GEO by an annealing process. With three separate approaches under consideration, elimination of the solar array radiation degradation concerns appears to be credible for the 1990 and beyond time frame. The following simplistic approach is utilized to obtain the best case $COTV_L$ characteristics:

	Nominal Case	Change	Minimum Case
Basic SPS module mass, tons	4875	per EY	2813
Oversizing for array degradation, tons	634	0% re 13%	0
"Scar" for EPDS & Structure	244	4% re 5%	113
Propulsion system mass	829	15% re 17%	422
Argon propellant @ 5000 sec	1291	η = 70% re 65%	610
O_2/H_2 ACS propellant	341	6% re 7%	169
Start-burn mass	8214		4127
COTV OBF	1.69		1.47

Similarly, cost per flight is scaled with start-burn mass and all COTV hardware assumed to be expended on the single mission.

$$\text{Cost per flight} = 88 \left(\frac{4127}{8214}\right) \left(1 - \frac{6}{88}\right) = 41\text{M (no satellite resize penalty)}$$

$$\text{Cost per SPS} = \$.65 \times 10^9 \text{ for COTV purchase}$$

For the "worst case" self-powered transfer from LEO to GEO a simplistic approach is utilized again for characterization.

	Nominal Case	Change	"Maximum" Case
Basic SPS module mass, tons	4875	per EY	7060
Oversizing for array degradation, tons	634	18% re 13%	1271
"Scar" for EPDS & Structure	244	7% re 5%	494
Propulsion system mass	829	20% re 17%	1413

	Nominal Case	Change	"Maximum" Case
Argon propellant @ 5000 sec	1291	η = 55% re 65%	2334
O_2/H_2 ACS propellant	341	15% re 7%	1059
Start-burn mass	8214		133634
COTV OBF	1.69		1.93

Similarly, cost per flight is scaled with start-burn mass and all COTV hardware assumed to be expended on the single mission.

$$\text{Cost per flight} = 88 \left(\frac{13364}{8214}\right) = \$146M$$

Cost per SPS = $\$2.3x10^9$ for COTV purchase

All three cases are planned to be refined by subsequent analysis, including the expected thruster characterization data to be provided by Lewis Research Center on the ion engine and Princeton University data on the MPD. Numberous other concepts for the COTV may emerge as attractive candidates, including "mixed mode" thermal/MPD arc jet as suggested by M. Lausten of JSC or perhaps "mass drivers" as suggested by Dr. O'Neill of Princeton.

In order to derive the effects upon SPS transportation costs for a constant mass SPS, this preliminary analysis was repeated for a constant 78,000 ton mass 10 GW SPS. Results of this analysis are tabulated below:

	Minimum		Nominal		Maximum	
Basic SPS Module, tons	1/16	4875	1/16	4875	1/16	4875
Oversize for Array Degradation	0%	0	13%	634	18%	878
"Scar" for EPDA & Structure	4%	195	5%	244	7%	341
Propulsion System Mass	15%	731	17%	829	20%	975
Argon Propellant @ 5000 sec	η=70%	1091	η=65%	1291	η=55%	1667
O_2/H_2 ACS Propellant	6%	293	7%	341	15%	731
Total Start-Burn Mass		7185		8214		9467
Orbit Burden Factor		1.47		1.69		1.94
Cost Per Flight		$72M		$88M		$101M

The assumption of no solar array degradation for the "minimum" case opens up the possibility of a dedicated solar array as an integral part of the COTV for return of the COTV utilizing the high specific impulse argon ion system rather than chemical propulsion. Additionally, this assumption may permit electric propulsion of inert payloads for geosynchronous orbit construction. Future analyses will treat these possibilities.

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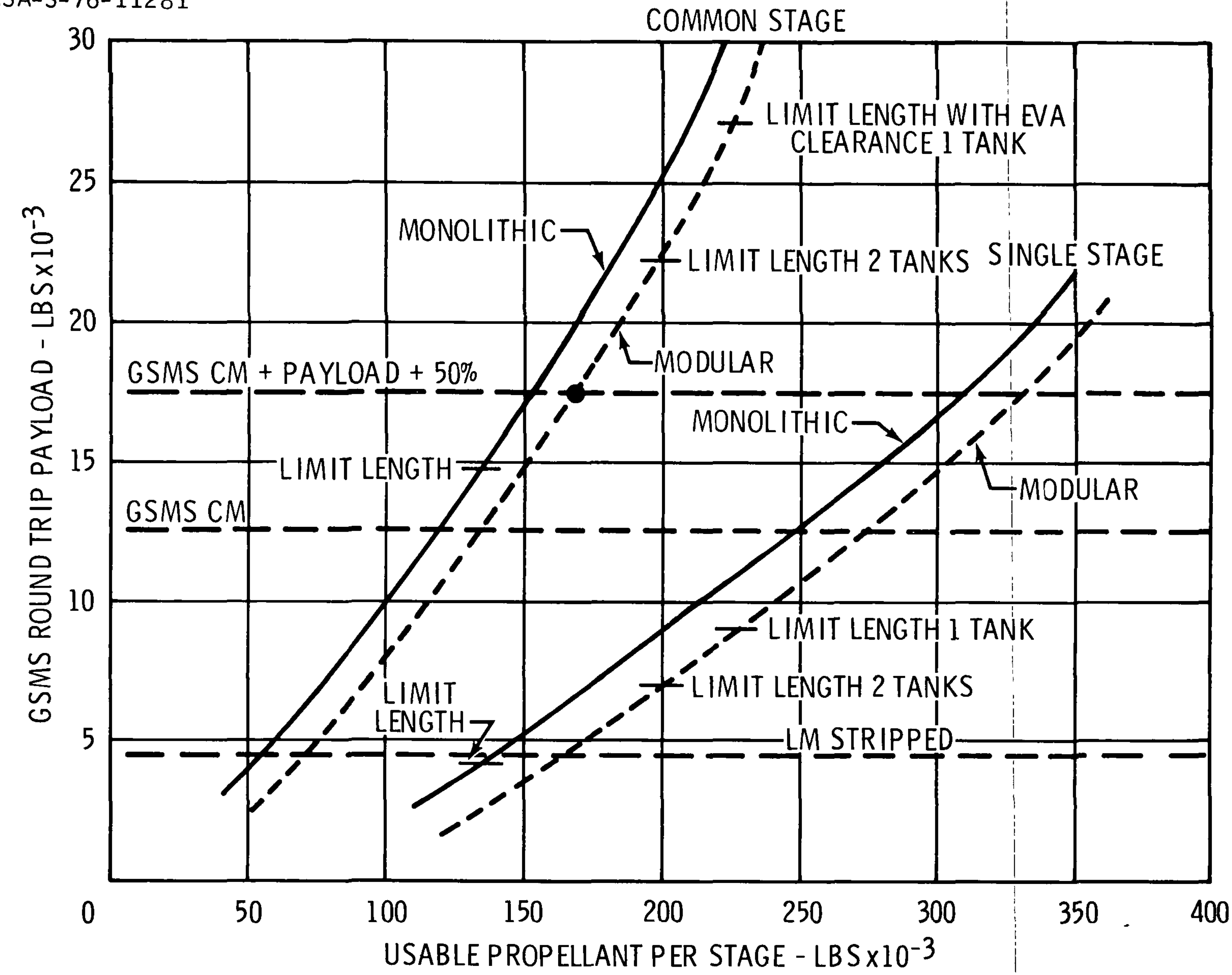
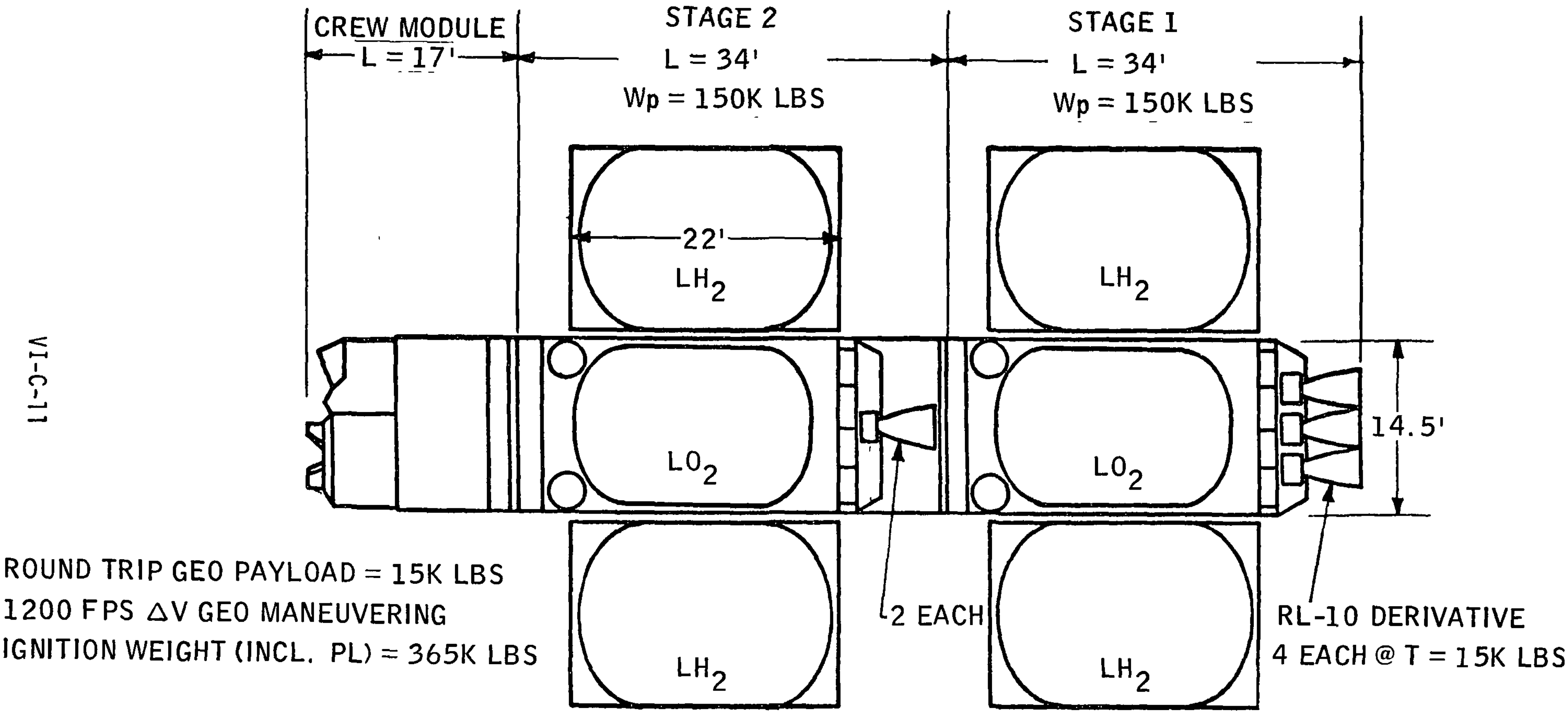


Figure VI-C-1. GSMS POTV Parametrics



- SPACE-BASED, ALL-PROPULSIVE CONCEPT
- INITIAL MISSION REQUIRES 7 SHUTTLE LAUNCHES
- ON-ORBIT TURNAROUND (REFUELING) REQUIRES 6 SHUTTLE LAUNCHES OR 2 HLLV LAUNCHES AND 1 SHUTTLE LAUNCH

Figure VI-C-?. Modular Common Stage POTV Configuration

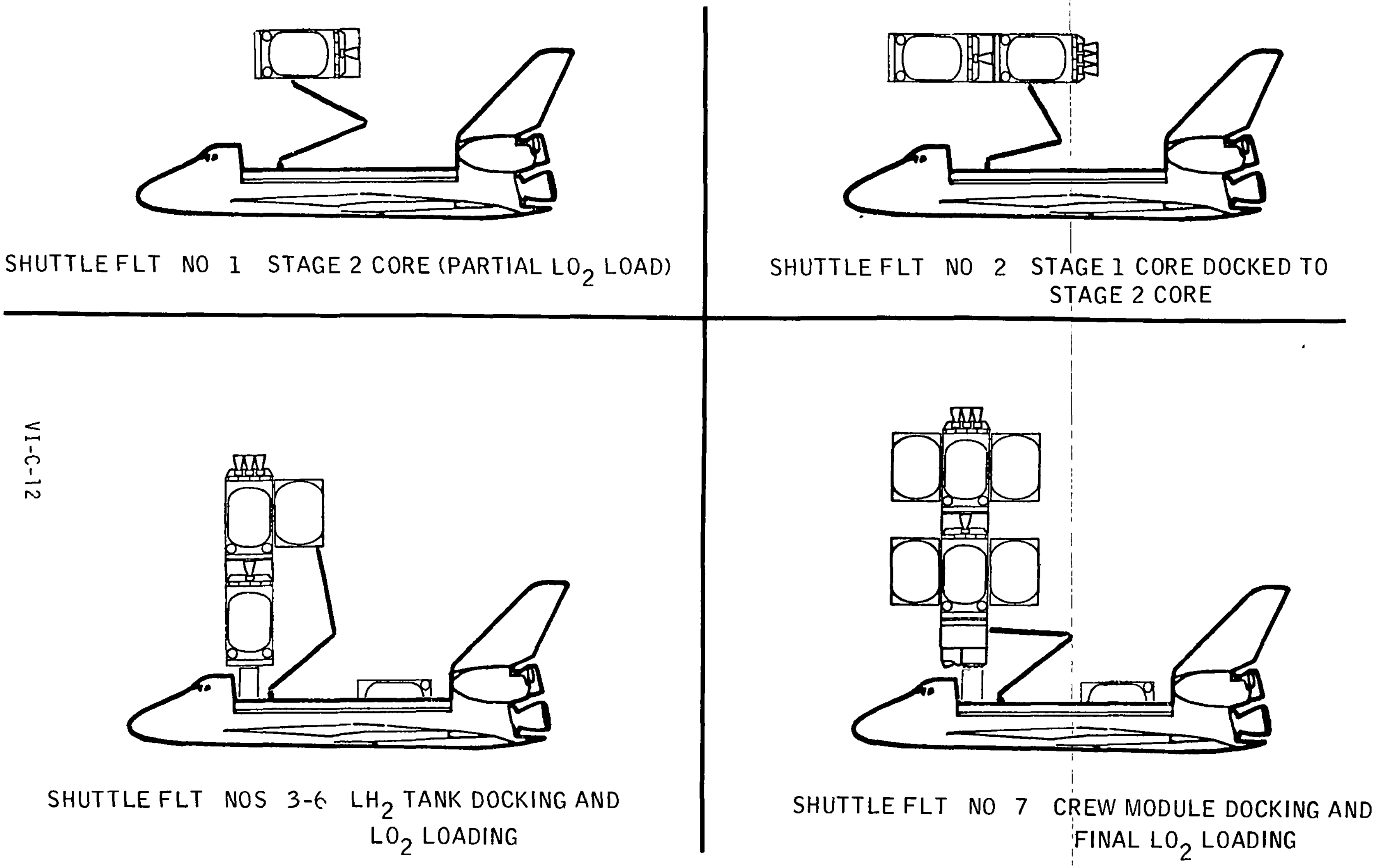
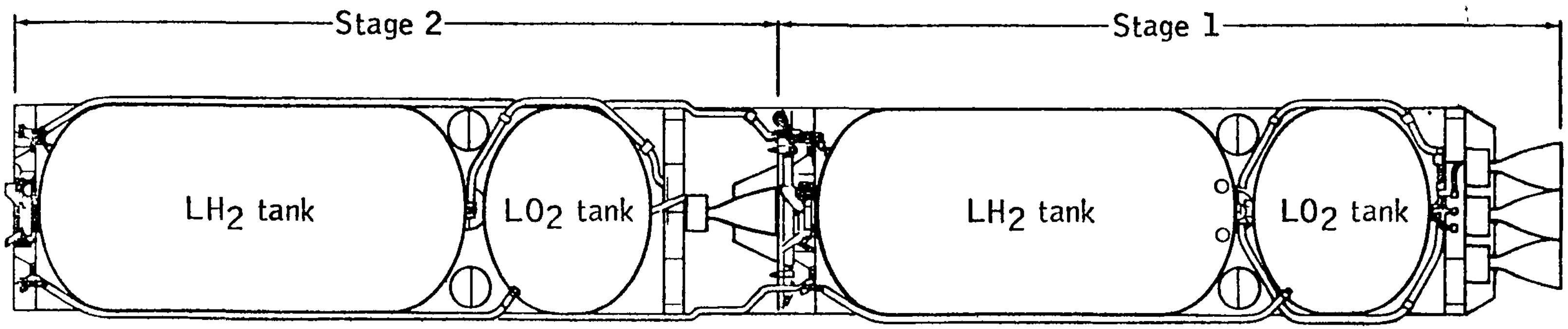


Figure VI-C-3. Modular Common Stage POTV On-Orbit Assembly Sequence, Shuttle Supported



Common stage LO_2/LH_2

Life: 50 missions

Payload: 75 passengers + 20 tons (up)
75 passengers (down)
(2nd stage GEO refuel)

Length:	33.28 m
Diameter:	4.42 m
Total weight:	121 tons
Propellant weight:	105 tons
Number of engines at 66 720 N each:	
Stage 1 :	4 engines
Stage 2 :	2 engines

Figure VI-C-4. Personnel Orbit Transfer Vehicle (POTV) Characteristics

No. of passengers	Dimension "A" length, m	Gross weight, tons
50	8.88	13.44
75	11.66	19.60
100	14.44	30.24

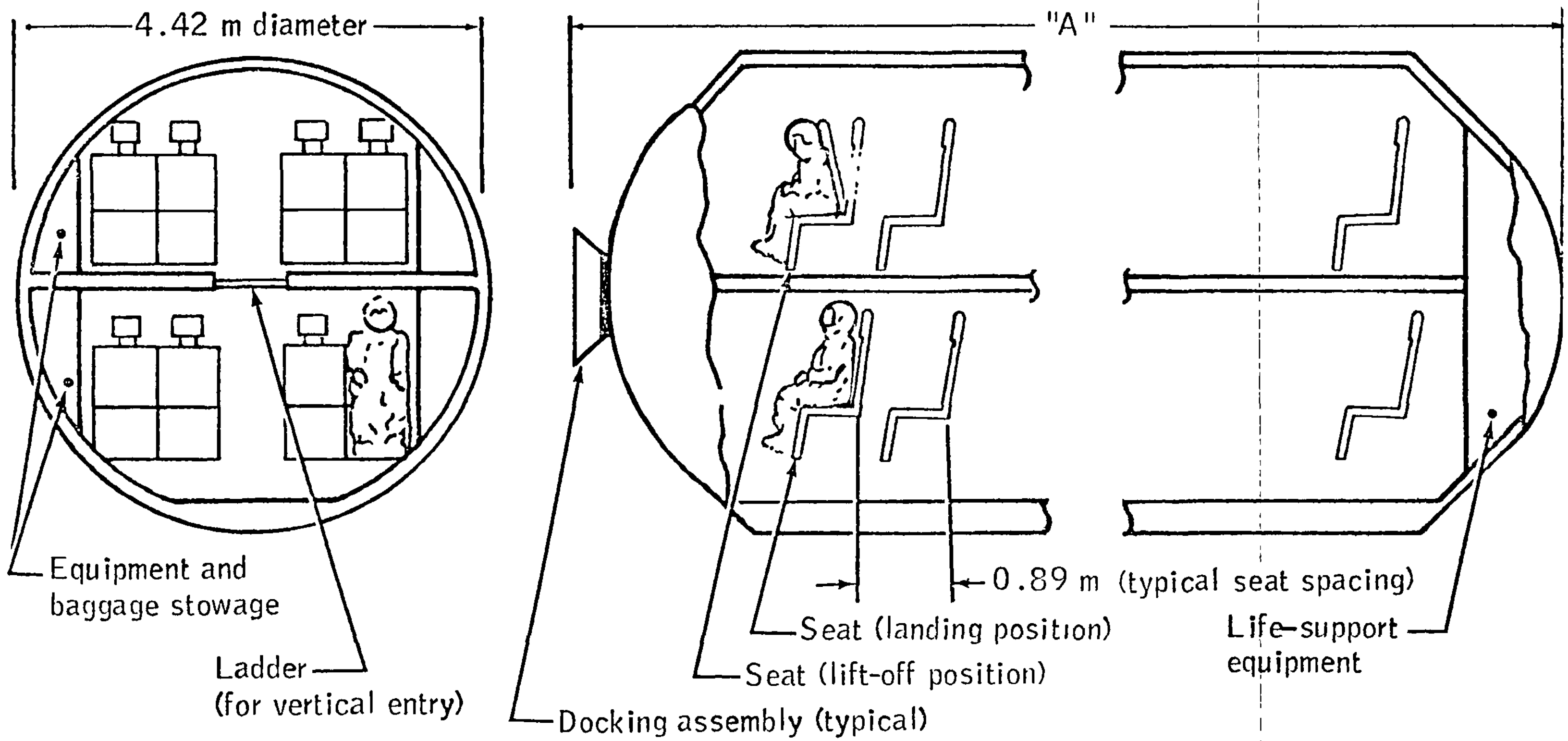


Figure VI-C-5. Crew Rotation Passenger Module

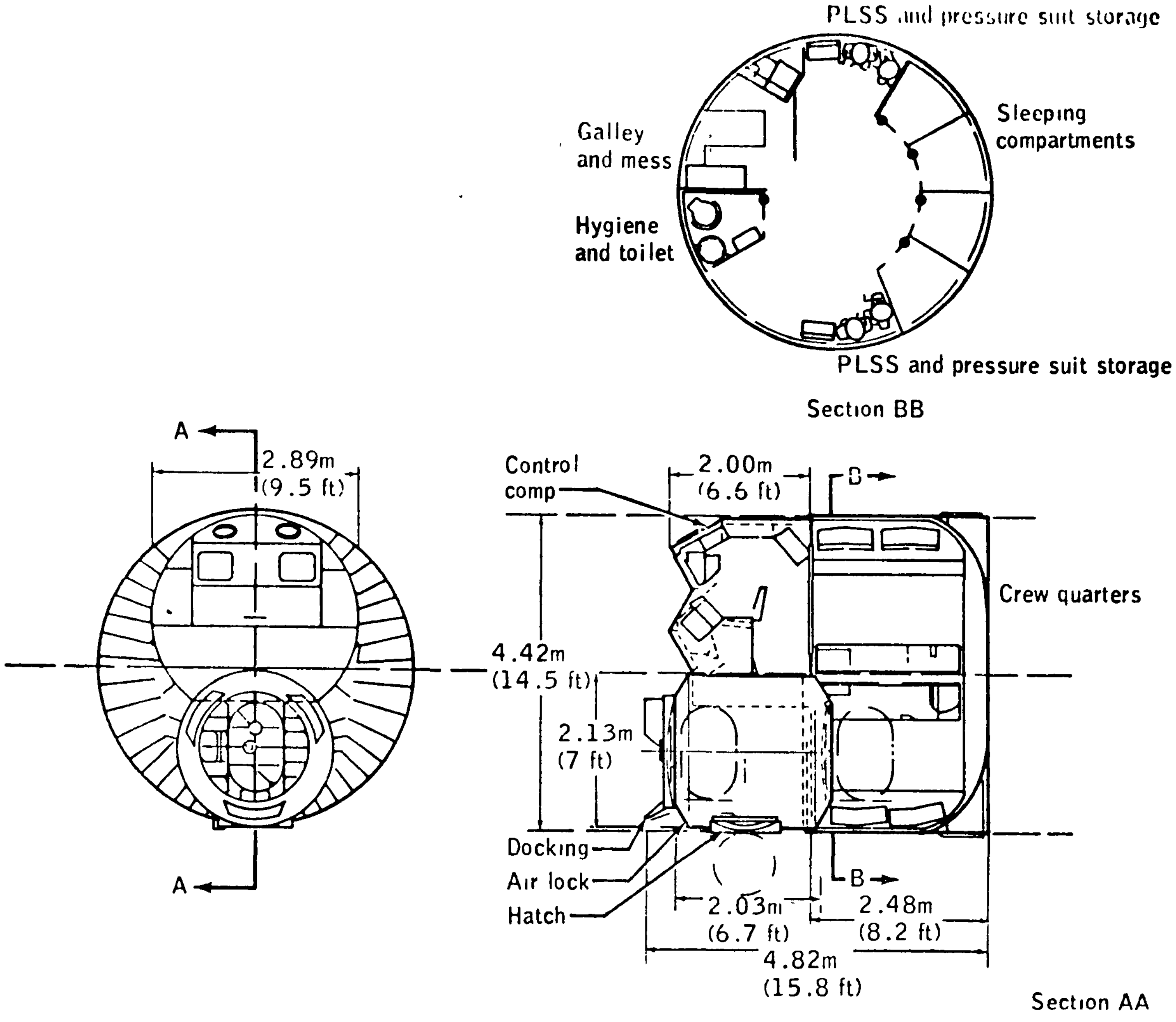


Figure VI-C-6. Crew Control Module Concept

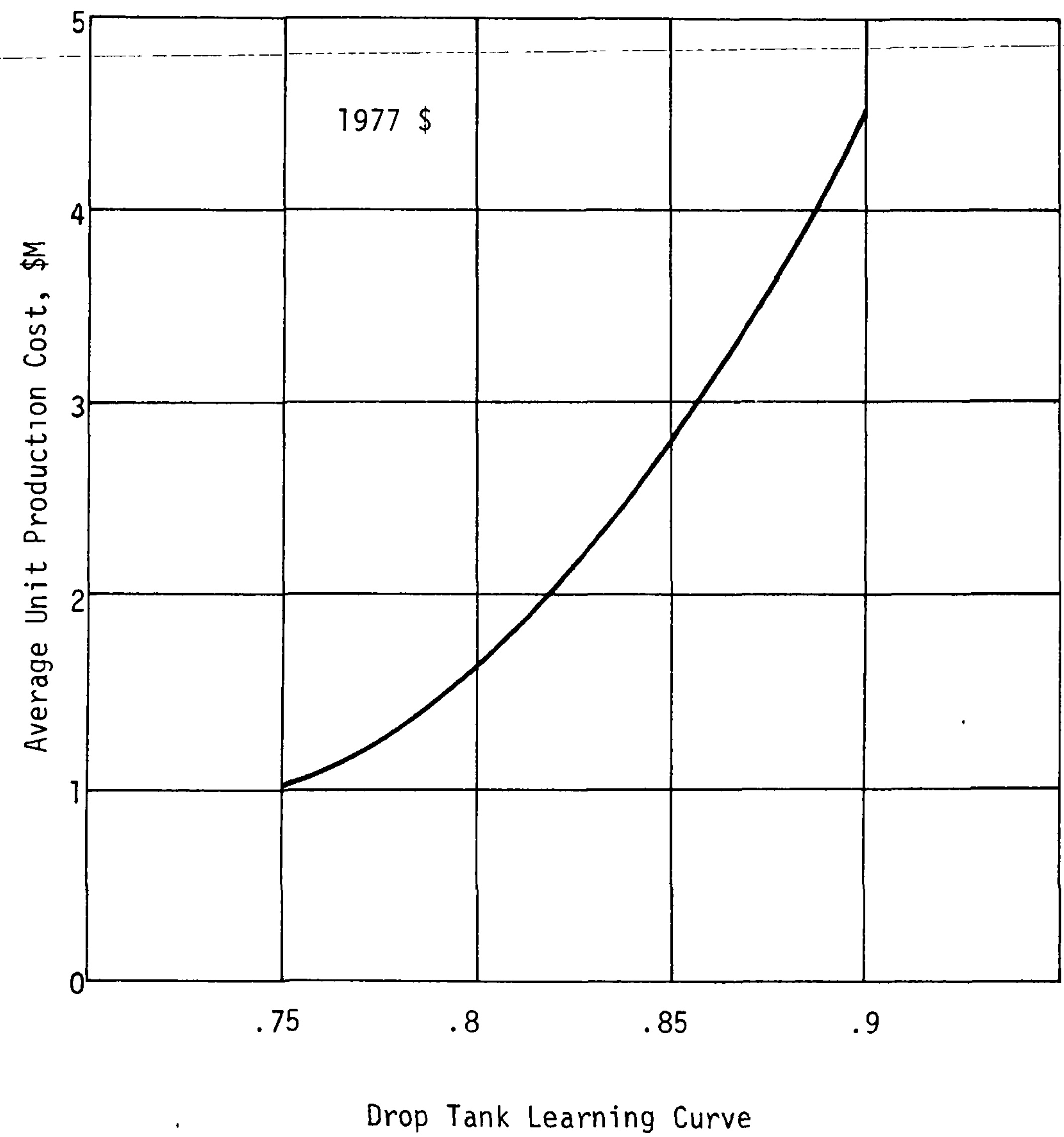


Figure VI-C-7. 2-1/2 Stage DT Average Unit Production Cost versus Learning Curve

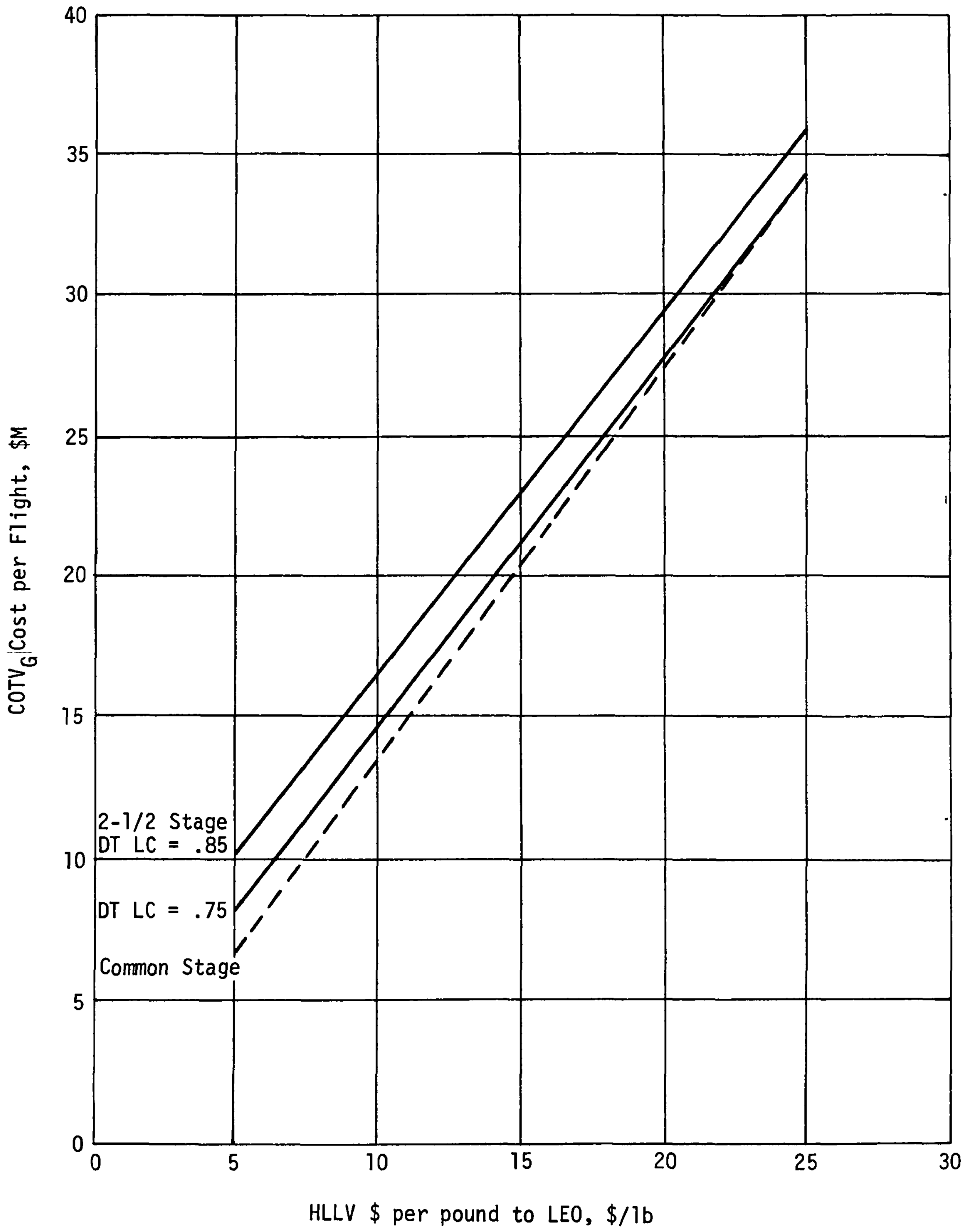
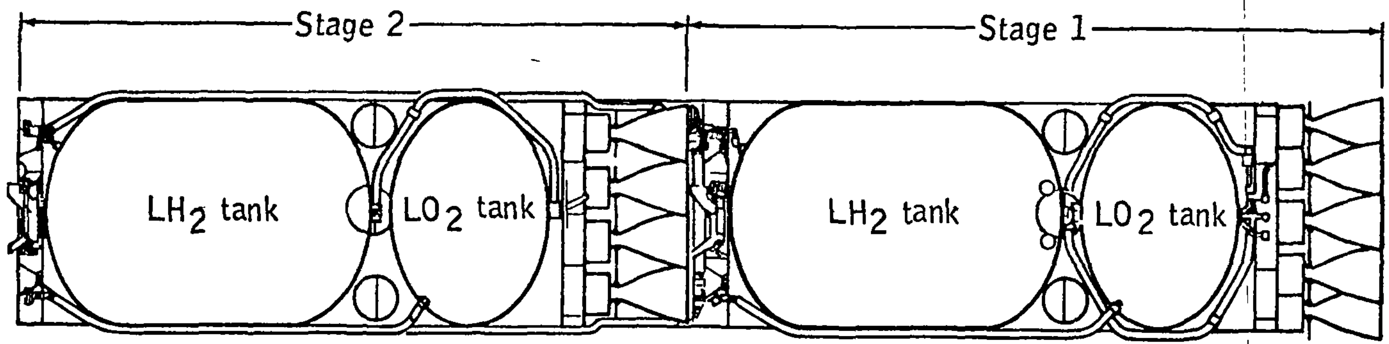


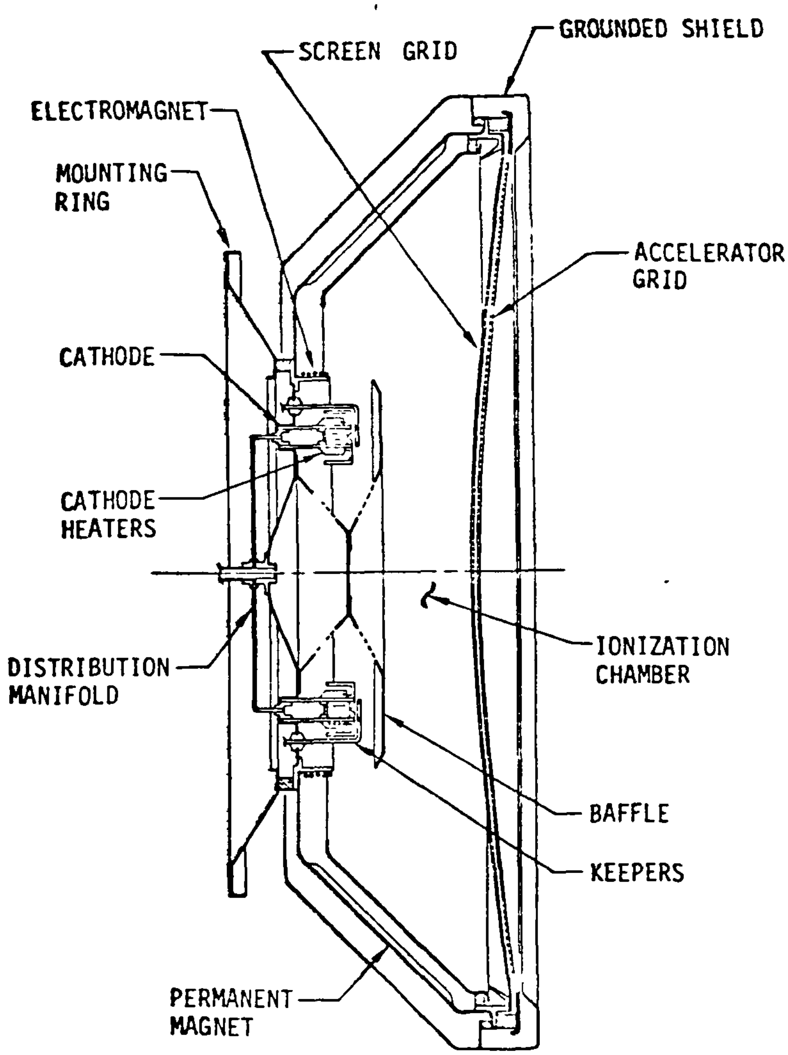
Figure VI-F-8. $COTV_G$ Cost per Flight versus HLLV $/LB to LEO



Common stage LO_2/LH_2
Life: 50 missions
Payload: 250 tons

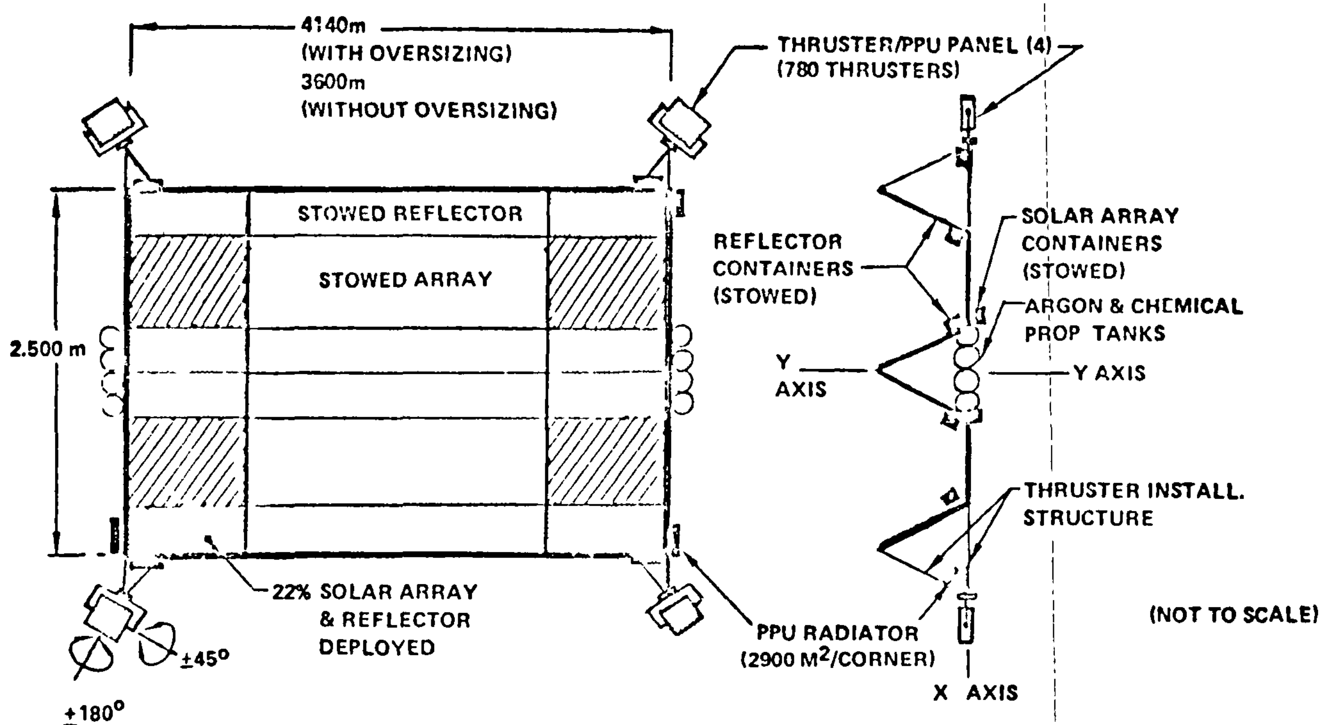
Length: 51.4 m
Diameter: 8.4 m
Total weight: 610 tons
Propellent weight: 564 tons

Figure VI-C-9. Cargo Orbit Transfer Vehicle ($COTV_G$) Characteristics



NOTE: FLOW CONTROL VALVE, ISOLATOR AND NEUTRALIZER(S) NOT SHOWN

Figure VI-C-10. 120 CM Argon Ion Thruster (Boeing)



MASS PROPERTIES SUMMARY

SATELLITE MODULE (10^6 Kg)		ORBIT TRANSFER SYSTEM (10^6 Kg)	
• BASIC	5 56	• DRY	0 95
• SELF POWER MODIFICATIONS	1 0	• ARGON PROP	1 53
		• LO_2/LH_2 PROP	0 40

• Iyy Ixx = $3\ 78 \times 10^{12}$ KgM

Figure VI-C-11. Typical Ion Electric Propulsion Configuration Photovoltaic Satellite (10 GW BOL) (Boeing)

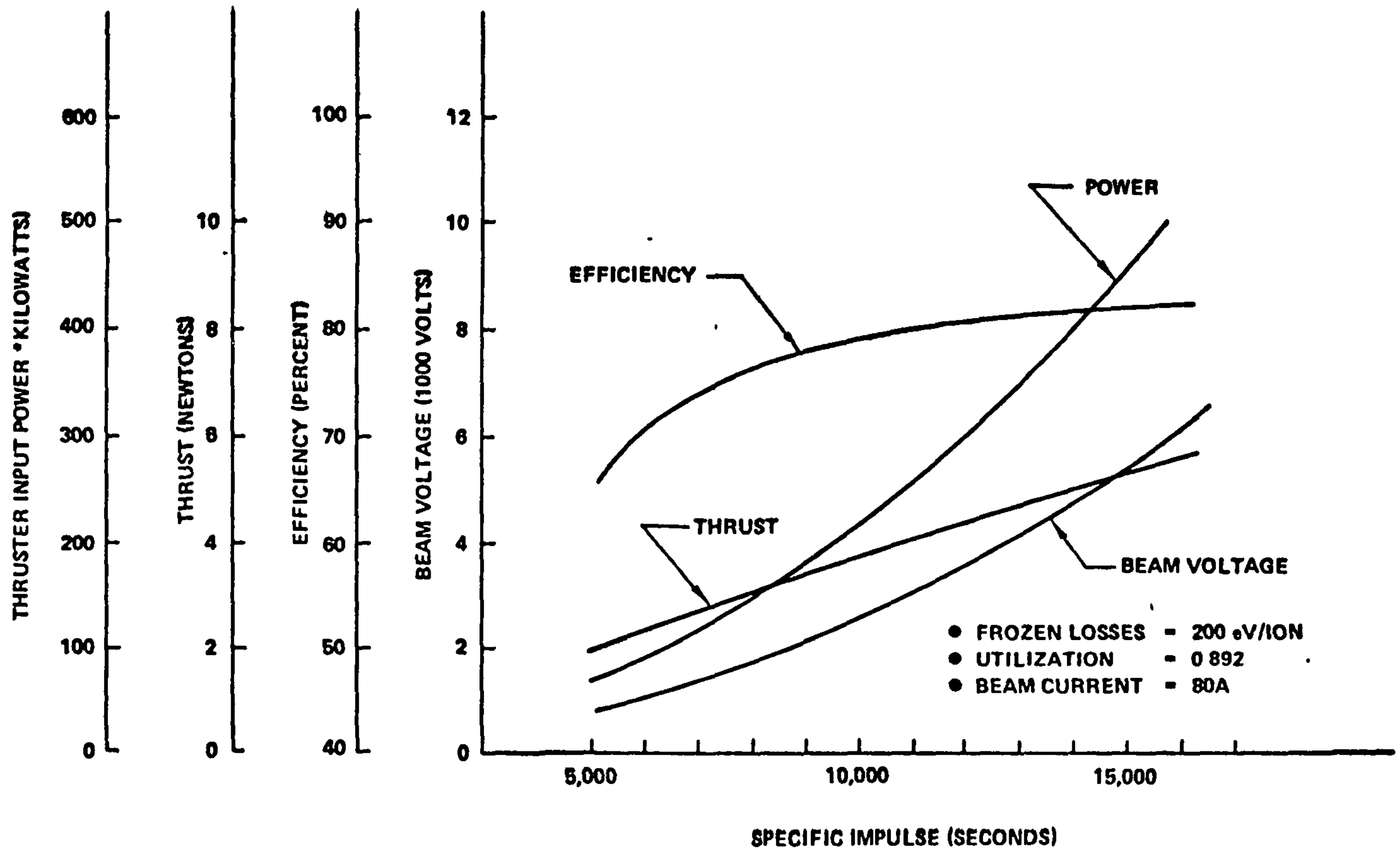


Figure VI-C-12. 120-CM Argon Ion Thruster Performance (Boeing)

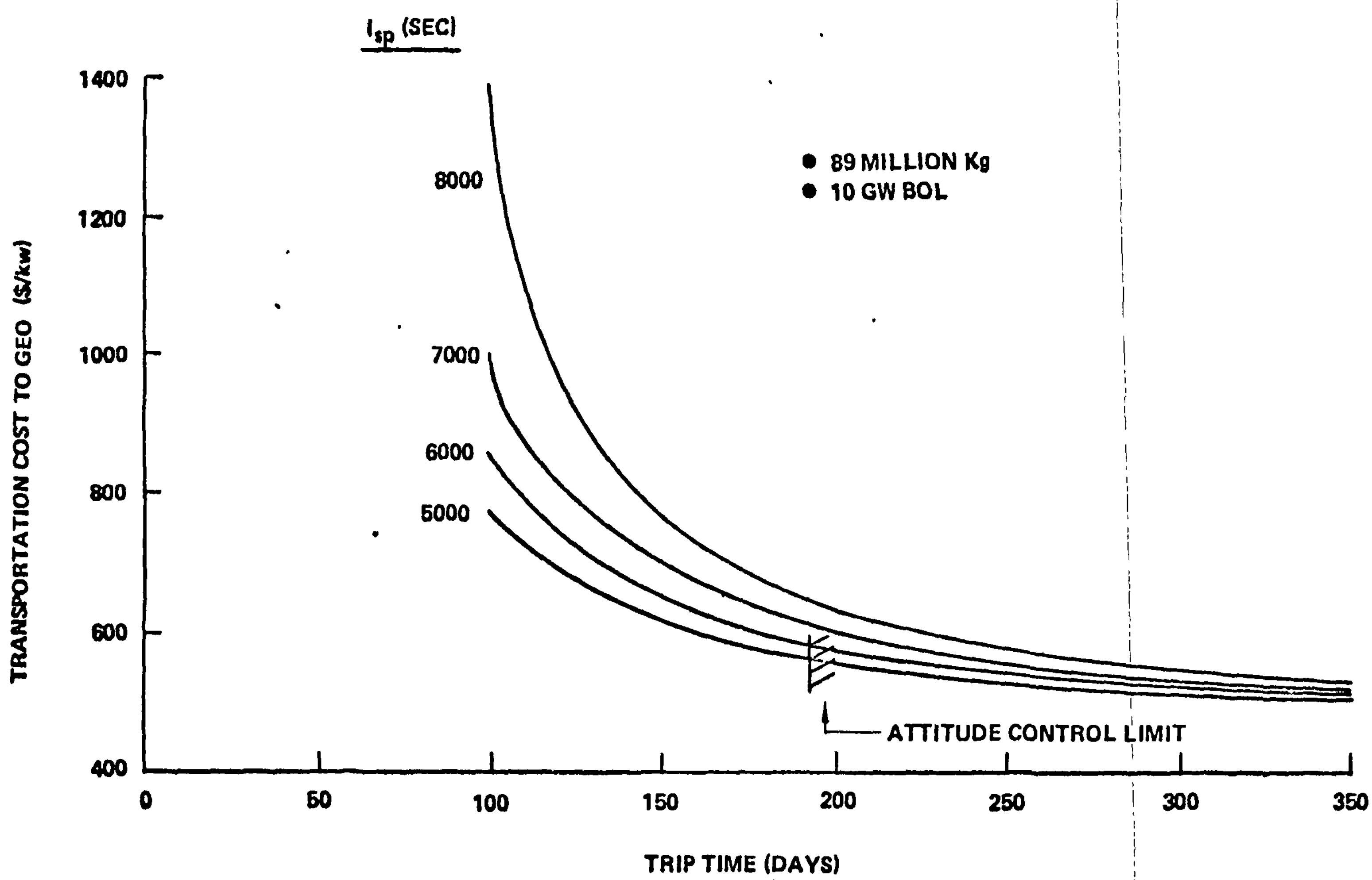


Figure VI-C-13. Isp and Trip Time Optimization Reference Photovoltaic Satellite (Boeing)

TABLE VI-C-1

OTV Propellant Handling Losses
SPS LEO Assembly, $COTV_L$

Mission Phase	Duration	Remarks	Propellant Loss % Argon	Hydrogen	Oxygen
Ground hold ascent to LEO	3 Min. 1 hr.		.5	1	.5
Dock with depot	3 hr.		1	2	1
Transfer to LEO storage		Modular tanks; no liquid transfer	0	0	0
LEO storage	6 days	No relique-faction	1	2	1
Transfer to OTV		Modular tanks; no liquid transfer	0	0	0
OTV Flight to GEO	6 Mon.	No relique-faction, pro-pulsion uses gas	3	5	3
Subtotal			5.5	10.0	5.5
Bulk Mass Subtotal				5.6	
Contingency (25%)				1.4	
Total				7.0	

TABLE VI-C-2

OTV Propellant Handling Losses
SPS GEO Assembly, $POTV_G$

Mission Phase	Duration	Remarks	Propellant Loss % LEO Fueling Hydrogen	Propellant Loss % LEO Fueling Oxygen	Propellant Loss % GEO Fueling Hydrogen	Propellant Loss % GEO Fueling Oxygen
Ground hold, ascent to LEO	3 Min. 1 Hr.		1	.5	1	.5
Dock with depot	3 Hr.		2	1	2	1
Transfer to LEO storage		Modular tanks; no liquid transfer	0	0	0	0
LEO storage	6 days	No relique-faction	2	1	2	1
Transfer to OTV:	1 Hr.					
Chilldown			2	1	2	1
Residuals			.3	.3	.3	.3
GEO storage	3 Mon.		-	-	5	3
GEO refuel stage 2: residuals	1 Hr.	No chilldown	-	-	1	1
Subtotal			7.3	3.8	13.3	7.8
Bulk Mass Subtotal			4.3		8.6	
Contingency (25%)			1.1		2.2	
Total			5.4		10.8	

TABLE VI-C-3

OTV Propellant Handling Losses
SPS LEO Assembly, $POTV_L$

Mission Phase	Duration	Remarks	Propellant Loss % LEO Fueling Hydrogen	LEO Fueling Oxygen	GEO Fueling Hydrogen	GEO Fueling Oxygen
Ground Hold, ascent to LEO	3 Min. 1 Hr.		1	.5	1	.5
Dock with depot	3 Hr.		2	1	2	1
Transfer to LEO storage		Modular tanks; no liquid transfer	0	0	0	0
LEO storage	6 days	No relique-faction	2	1	2	1
Transfer to OTV:	1 Hr.					
Chilldown			2	1	2	1
Residuals			.3	.3	.3	.3
COTV Flight to GEO with prop. cargo	6 Mon.		-	-	10	6
GEO Storage	3 Mon.		-	-	5	3
GEO refuel stage 2: residuals	1 Hr.	No chilldown	-	-	1	1
Subtotal			7.3	3.8	23.8	13.8
Bulk Mass Subtotal			4.3		15.2	
Contingency (25%)			1.1		3.8	
Total			5.4		19.0	

TABLE VI-C-4

OTV Propellant Handling Losses
SPS GEO Assembly, $COTV_G$

Mission Phase	Duration	Remarks	Propellant Loss % Hydrogen	Oxygen
Ground hold, ascent to LEO	3 Min. 1 Hr		1	.5
Dock with depot	3 Hr.		2	1
Transfer to LEO storage		Modular tanks; no liquid transfer	0	0
LEO storage	6 days	No reliquefaction	2	1
Transfer to OTV:				
Childown			2	1
Residuals			1	1
Subtotal			8	4.5
Bulk Mass Subtotal			4.9	
Contingency (25%)			1.2	
Total			6.1	

TABLE VI-C-5

POTV Main Propulsion Mission Delta Velocity Budgets

		GSMS (FPS)	Crew Rotation/Resupply (FPS)	
	LEO Parking Orbit (NM, degrees)	150x150, 28.5°	270x270, 28.5°	258x258, 31°
1.	LEO first injection burn	4270	4270	4270
2.	LEO second injection burn	3786	3586	3615
	Estimated gravity losses	190	190	190
3.	GEO circularization burn (19,323x19,323 NM, 0°)	5851	5798	5979
4.	GEO rendezvous and docking	131	131	131
5.	45° longitude shift, rendezvous	1278	--	--
6.	GEO deorbit burn Return orbit	5840 (175x19323 NM)	5798 (270x19323 NM)	5979 (258x19323 NM)
7.	LEO circularization burn	8014	7856	7885
	Estimated gravity losses	50	50	50
8.	LEO rendezvous and docking	131	131	131
9.	Flight performance reserves 2% total delta-velocity	591	556	564
	TOTAL DELTA-VELOCITY	30,132	28,366	28,784

TABLE VI-C-6

Preliminary Weight Statement
POTV Reference Configuration - Common Stage O_2/H_2
GEO Crew Rotation/Resupply

	Stage 1, lbs	Stage 2, lbs
Dry Mass	(13,210)	(15,210)
Structures and Mechanisms	4,650	4,850
Main Propulsion	3,190	2,270
Thermal Control	1,070	1,180
Auxiliary Propulsion	480	2,630
Avionics	560	560
EPS	620	680
Contingency (25%)	2,640	3,040
Unusable Fluids	(860)	(1,340)
LO_2	370	360
LH_2	390	380
APS	100	600
Stage Burnout	(14,070)	(16,550)
Inflight Expendables	(117,460)	(119,430)
EPS Reactant	90	420
Boil Off	110	440
Start/Stop Losses	110	120
APS Impulse Propellant	950	2,570
Main Impulse Propellant	116,200	115,880
Stage Ignition lbs (metric tons)	131,530 (59.66)	135,980 (61.67)
Vehicle Ignition lbs (metric tons)	267,510 (121.32)	

	JSC (FY76)	MDAC (SSSAS)	BOEING (FSTSA)
Wp PER STAGE			
USABLE	115,850	126,116	98,000
LOADED	117,300	129,081	99,000
λ'_1	883	902	888
λ'_2	.829	910	.837
PROPULSION	CAT IVB, 462 @ 6:1 2 ON 2ND STG 4 ON 1ST STG	CAT IIA, 459 @ 6:1 1 ON 2ND STG 2 ON 1ST STG	20K SPACE ENGINES 2 ON 2ND STG 4 ON 1ST STG
IGNITION WEIGHT	270,920	278,372	227,515
PAYLOAD CAPABILITY			
DELIVERY	66,000	109,917	60,000
ROUND TRIP	13,200	29,321	13,000
MANNED MODULE WEIGHT			
4 MEN 10 DAYS; 90 DAYS	13,119; ___	11,700; 14,500	12,480; ___
12 MEN 10 DAYS; 90 DAYS	___; ___	22,700; 30,400	___; ___
COST			
RDT&E	$478M	$378.7M	$307 9M
PROD	$31M (TFU)	$31.9M (@ 3 UNITS/YR)	$39.6 (TFU)
OPERATIONS/FLT	--	$.325M (@ 8 FLTS/YR)	--

Table VI-C-7. Comparison of POTV Configurations

TABLE VI-C-8

Main Propulsion Delta-Velocity Budget
Payload Delivery by $COTV_G$

		Mission Delta-V (FPS)	Stage 1 Delta-V (FPS)	Stage 2 Delta-V (FPS)
	LEO parking orbit (477.5x477.5 KM, 31^{o})			
1.	LEO first injection burn	4270	4270	--
2.	LEO second injection burn	3615	1730	1885
	Injection & circularization burns gravity losses	190	--	190
3.	GEO circularization burn (19,323x19,323 NM, 0^{o})	5979	--	5979
4.	GEO rendezvous and docking	131	--	131
5.	GEO deorbit burn (270x19,323 NM, 26.3^{o})	5979	--	5979
6.	LEO circularization burn (270x270 NM, 28.5^{o})	7885	6000	7885
	Deorbit and circularization burns gravity losses	50	50	50
7.	LEO rendezvous and docking	131	131	131
8.	Flight performance reserces (2% total Delta-V)	565	244	445
	TOTAL DELTA-VELOCITY (FPS)	28,795	12,425	22,675
	(Meters/Sec)	8,776	3,787	6,911

TABLE VI-C-9

Preliminary Mass Properties*
Common Stage LO_2/LH_2 $COTV_G$

	Stage 1 (lbs)	Stage 2 (lbs)
Dry Mass	(41,000)	(38,920)
Structure and Mechanisms	19,800	20,400
Main Propulsion	10,200	7,300
Thermal Control	2,300	2,750
Electrical Power	1,020	1,160
Auxiliary Propulsion	1,700	1,600
Avionics	630	630
Contingency (15%)	5,350	5,080
Unusable Fluids	(3,930)	(4,360)
LO_2	1,600	1,600
LH_2	1,930	1,930
APS	400	830
Stage Burnout	(44,930)	(43,280)
Inflight Expendables	(626,750)	(631,170)
Boil-off	330	1,300
Start/Stop Losses	920	870
APS Impulse Propellant	4,000	7,500
Main Impulse Propellant	621,500	621,500
Stage Ignition Weight	(671,680)	(674,450)
Stage Mass Fraction	.925	.921

*Parametrically derived from FSTSA Vol. III, Sect. 3.1 (NAS 9-14323), dated December 31, 1976.

TABLE VI-C-10

Preliminary Mass Properties*
2-1/2 Stage LO_2/LH_2 $COTV_G$

	Stage 1 (lbs)	Stage 2 Core (lbs)	Stage 2 DT (lbs)
Dry Mass	(38,380)	(23,950)	(23,790)
Structure and Mechanisms	18,500	10,200	16,200
Main Propulsion	9,200	6,400	1,840
Thermal Control	2,570	1,020	2,200
Electrical Power	950	1,100	300
Auxiliary Propulsion	1,530	1,510	--
Avionics	620	600	150
Contingency (15%)	5,010	3,120	3,100
Unusable Fluids	(3,610)	(1,030)	(3,230)
LO_2	1,450	110	1,450
LH_2	1,780	140	1,780
APS	380	780	--
Stage Burnout	(41,990)	(24,980)	(27,020)
Inflight Expendables	(573,560)	(49,950)	(569,320)
Boil-off	320	250	320
Start/Stop Losses	640	700	--
APS Impulse Propellant	3,600	7,100	--
Main Impulse Propellant	569,000	41,900	569,000
Stage Ignition Weight	(615,550)	(74,930)	(596,340)
Stage Mass Fraction	.924	.559	.954

*Parametrically derived from FSTSA Vol. III, Sect. 3.1 (NAS 9-14323), dated December 31, 1976.

TABLE VI-C-11

Preliminary Cost Estimate*
Common Stage LO_2/LH_2 $COTV_G$

	1977 $M	
	DDT&E	TFU
Flight Hardware	(184.7/16.6)	(44.7/34.0)
Structures & Mechanisms	18.2/3.0	5.7/4.6
Main Propulsion (less engines)	14.4/4.6	1.4/.8
Auxiliary Propulsion	12.9/3.4	5.7/3.9
Avionics	12.6/3.5	12.6/10.5
Electrical Power	4.2/1.1	3.2/2.6
Thermal Control	7.9/1.0	4.2/2.9
Assembly and Checkout	--	1.5/1.3
Engines	114.5/--	10.4/7.4
System Engineering and Integration	9.3/2.5	--
Software Engineering	7.2/1.9	--
Test Hardware	(178.9/136.0)	--
Ground Test Hardware (2-1/2 sets)	111.8/85.0	--
Flight Test Hardware (1-1/2 sets)	67.1/51.0	--
Systems Test Labor and GSE	15.1/4.2	--
Initial Tooling	2.0/1.5	--
Program Management (6%)	23.9/9.8	2.7/2.0
Subtotal	(421.1/172.5)	(47.4/36.0)
Cost Contingency (11%)	46.3/19.0	5.2/4.0
Total	(467.4/191.5)	(52.6/40.0)

*Parametically derived from FSTSA Vol. III, Sect. 6.3 (NAS 9-14323), dated December 31, 1976.

TABLE VI-C-12

Preliminary Cost Estimate*
2-1/2 Stage LO_2/LH_2 $COTV_G$

	Stage 1 Stage 2 Core/Stage 2 DT 1977 $M DDT&E	TFU
Flight Hardware	(182.6/13.9/12.1)	(42.4/28.2/10.5)
Structures and Mechanisms	16.9/1.7/5.7	5.3/2.4/4.2
Main Propulsion (less engines)	12.6/4.0/3.7	1.3/.8/.5
Auxiliary Propulsion	13.8/3.4/--	5.4/3.7/--
Avionics	12.7/3.4/.4	11.6/10.2/.5
Electrical Power	4.2/.9/.5	2.9/2.5/.7
Thermal Control	7.9/.5/1.8	4.6/1.8/4.2
Assembly and Checkout	--	1.7/.4/.4
Engines	114.5/--/--	--
System Engineering & Integration	8.9/2.1/1.9	--
Software Engineering	6.7/1.6/1.4	--
Test Hardware	(169.6/112.8/42.1	--
Ground Test Hardware (2-1/2 sets)	106.0/70.5/26.3	--
Flight Test Hardware (1-1/2 sets)	63.6/42.3/15.8	--
Systems Test Labor and GSE	15.4/3.5/2.9	--
Initial Tooling	2.0/1.3/.2	--
Program Management (6%)	23.1/8.1/3.6	2.5/1.7/.6
Subtotal	(408.3/143.3/64.2)	(44.9/29.9/11.1)
Cost Contingency (11%)	44.9/15.8/7.1	4.9/3.3/1.2
Total	(453.2/159.1/71.3)	(49.8/33.2/12.3)

*Parametically derived from FSTSA Vol. III, Sect. 6.3 (NAS 9-14323), dated December 31, 1976.

TABLE VI-C-13

Cost per Flight
Common Stage LO_2/LH_2

ASSUMPTIONS:
1. 15,152 $COTV_G$ Flights support construction of 46 SPS
2. 50 missions life
3. 30% of max fleet size spare units (ground-based)
4. LH_2 = $.36/lb, LO_2 = $.021/lb
5. Learning curve = .88
6. 6.1% pre-flight propellant losses
7. HLLV cost/flt = $9.0M
8. 1977 $

TOTAL DDT&E = $658.9M
from Table VI-C-11
TOTAL TFU = 92.6M

TOTAL UNIT BUY = $\frac{15,152}{50} + 7 = 310$ units

AVERAGE UNIT PRODUCTION COST = $92.6\ (310)^{.88-1} = \$46.5M/unit$

AVERAGE UNIT/FLT = $\frac{46.5}{50}$ = $\underline{\$.9M/flt}$

PROPELLANT $/FLT = $\left(\frac{1,329,942}{7}\right) .36 + \left(\frac{1,329,942}{7}\right) 6 \times .021 = \underline{\$.1M/flt}$

PROPELLANT LAUNCH COSTS = $\frac{1,329,942}{934,920} \times 9 = \underline{\$12.8M/flt}$

HARDWARE LAUNCH COSTS = $\frac{310\ (41,000 + 38,920)}{934,920} \times 9 \div 15,152 + \underline{\$.02M/flt}$

TOTAL COST PER FLIGHT .9 + .1 + 12.8 + .02 = $\underline{\$13.8M/flt}$
(includes propellant launch)

TABLE VI-C-14

Cost per Flight
2-1/2 Stage LO_2/LH_2

ASSUMPTIONS:
1. 15,152 $COTV_G$ flights support placement of 46 SPS
2. 50 missions life for stage 1, stage 2 core; 1 mission life for stage 2 DT
3. 10% of max fleet size spare units for stage 1, stage 2 core; 5% of max fleet size spare units for stage 2 DT
4. LH_2 = \$.36/lb, LO_2 = \$.021/lb
5. Stage learning curve = .88, DT learning curve = .85
6. 7.3% pre-flight propellant losses
7. HLLV cost/flt = \$9.0M
8. 1977 \$

STAGE DDT&E = \$612.3M

DT DDT&E = \$71.3M

STAGE TFU = \$83.0M

DT TFU = \$12.3M

TOTAL UNIT BUY: $\frac{15,152}{50} + 7 = 310$ stages

$\frac{15,152}{1} + 1318\ (.05) = 15,218$ DT

AVERAGE UNIT PRODUCTION COST: $83\ (310)^{.88-1} = \$41.7\text{M/stage}$

$12.3\ (15,218)^{.85-1} = \$2.9\text{M DT}$

AVERAGE UNIT/FLT $\frac{41.7}{50}$ = \$.8M/flt (stage)

+ \$2.9M/flt (DT)

\$3.7M/flt

PROPELLANT \$/FLT: $(\frac{1,261,359}{7})\ .36 + (\frac{1,261,359}{7})\ 6 \times .021 = \$.1\text{/flt}$

PROPELLANT LAUNCH COSTS: $\frac{1,261,359}{934,920} \times 9 = \$12.1\text{M/flt}$

C-4

TABLE VI-C-14 (CONT'D)

$$\text{HARDWARE LAUNCH COSTS: } \frac{310\ (38{,}380 + 23{,}950)}{934{,}920} \times 9.0 \div 15{,}152$$

$$+ \frac{23{,}790}{934{,}920} \times 9.0 = \underline{\$.2M/flt}$$

TOTAL COST PER FLIGHT = 3.7 + .1 + 12.1 + .2 = $16.1M/flt

VI. SPACE TRANSPORTATION SYSTEM

D. ORBITAL TRANSFER MISSION ANALYSIS

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Occultation Effects and Impact on Self-powered Vehicle

Because the transfer starts from a low Earth orbit (LEO) at a relatively low inclination, the vehicle spends a portion of each of at least the low altitude orbits in the Earth's shadow (night). This occultation of the sun every few hours creates a special problem for the self-powered electric vehicles. For these cases at least part of the SPS is generating power for use by the thrusters. Thus, the entry into Earth's shadow results in a loss of system thrust.

For these self-powered vehicles the electric thrusters will provide both translational acceleration and also attitude control. Temporary loss of translational acceleration has minimal significance. Primarily it increases the total flight time by the length of time the system is in shadow (i.e., the time the thrusters are not operating).

Additude control loss is a different matter. The system cannot be gravity stabilized for attitude control because it must be oriented toward the sun to provide power. Consequently, considering the dimensions and mass of the power station combined with a quite limited thrust capability, it becomes apparent that active thrusting attitude control will have to be maintained more or less continuously.

There are two potential approaches to this problem. Either find low thrust transfer orbits with no shadow entry, or provide a backup attitude control system (ACS).

If the angle between the sun and the plane of the orbit is high enough, and the orbit is oriented correctly, the satellite will be totally in sunlight at a very low altitude. For instance, at winter (or summer) solstice when the sun makes an angle of 23.5° with the equator, an orbit with an inclination of only 45° can be oriented to be entirely in the sun at an altitude of only 250 n.mi. However, orbital nodal precession and the motion of the Earth around the sun both combine to rotate the orbit to where it intersects the shadow again within just a few days.

This precession effect means that the shadow intersection problem not only depends on initial date and orbit configuration but also on thrust level and flight time.

Figure VI-D-1 shows the percentage of total flight time (up to geosynchronous altitude) spent in darkness as a function of thrust level (and/or trip time). These are for several different inclinations all starting at the best possible time (winter solstice). The initial orbit orientation is same for all the orbits and is near optimum for the range of inclination examined.

The benefits of the high inclination winter departure are maintained as long as the thrust levels are more than about 10^{-4} g (flight time approx. 50 days). As the thrust levels fall below 10^{-4} g; however, it suddenly becomes impossible to avoid precession rotating the orbit in the Earth's shadow and the total time spent in orbit suddenly increases to around 10-15%.

Ion type engines have thrust to weight ratios on the order of 2 or 3 X 10^{-4} for Isp of around 5000 sec. That is for the engines alone. Total thrust to weight of the system should be about an order of magnitude less.

What this means is that the thrust to weight (T/W) we can expect from the high Isp systems will probably be around 5 x 10^{-5} g with a flight time approaching 6 months. At this thrust level and flight time, avoiding the shadow is impossible and approximately 10% of the transfer time will be in shadow.

With transfer times then, of 100 days and upwards, the primary advantages of starting at the solstice points or from a high inclination has been essentially lost.

The vehicle should have a backup chemical thruster system to provide attitude control when the SPS in in shadow. This system should not be used to provide delta-V thrusting. To do so would nearly double the total propellant usage while only decreasing the flight time by around 10%.

Departure should then take place whenever the SPS element is completed without trying to wait for the solstice. Inclinations should be as low as possible to minimize low orbit delivery costs and to minimize outbound delta-V and flight time.

High Thrust Orbital Mechanics in Comparison to Low Thrust

High thrust transfer equate to conventional chemical propulsion stages and synchronous orbit construction of the SPS. This should be a very standard conventional type operation using at least two propulsion stages from LEO both of which are returned and reused. For LOX/H_2 propellants (Isp approx. 450 sec) the propellant used each flight is around twice the weight of the payload delivered to synchronous orbit. This means that approximately 3 pounds of mass must be delivered to LEO for every pound that reaches GEO. Launch of this material to LEO would make up the bulk of the transportation costs for high-thrust operations.

Low-thrust transfer implies some sort of self-powered high Isp flight. This allows at least partial construction in low orbit. The total material in low Earth orbit is only about 1/2 as much as in the high thrust case. Operational complexity and the number of engineering

problems that must be solved are vastly greater than for the conventional high-thrust case. However, the tremendous reduction in lauch requirements plus the advantage of keeping most the manned construction in low orbit implies the possibility of significantly reduced total transportation costs.

SHADOW DWELL TIME FOR LOW THRUST TRANSFER TO GEOSYNCHRONOUS ALTITUDE

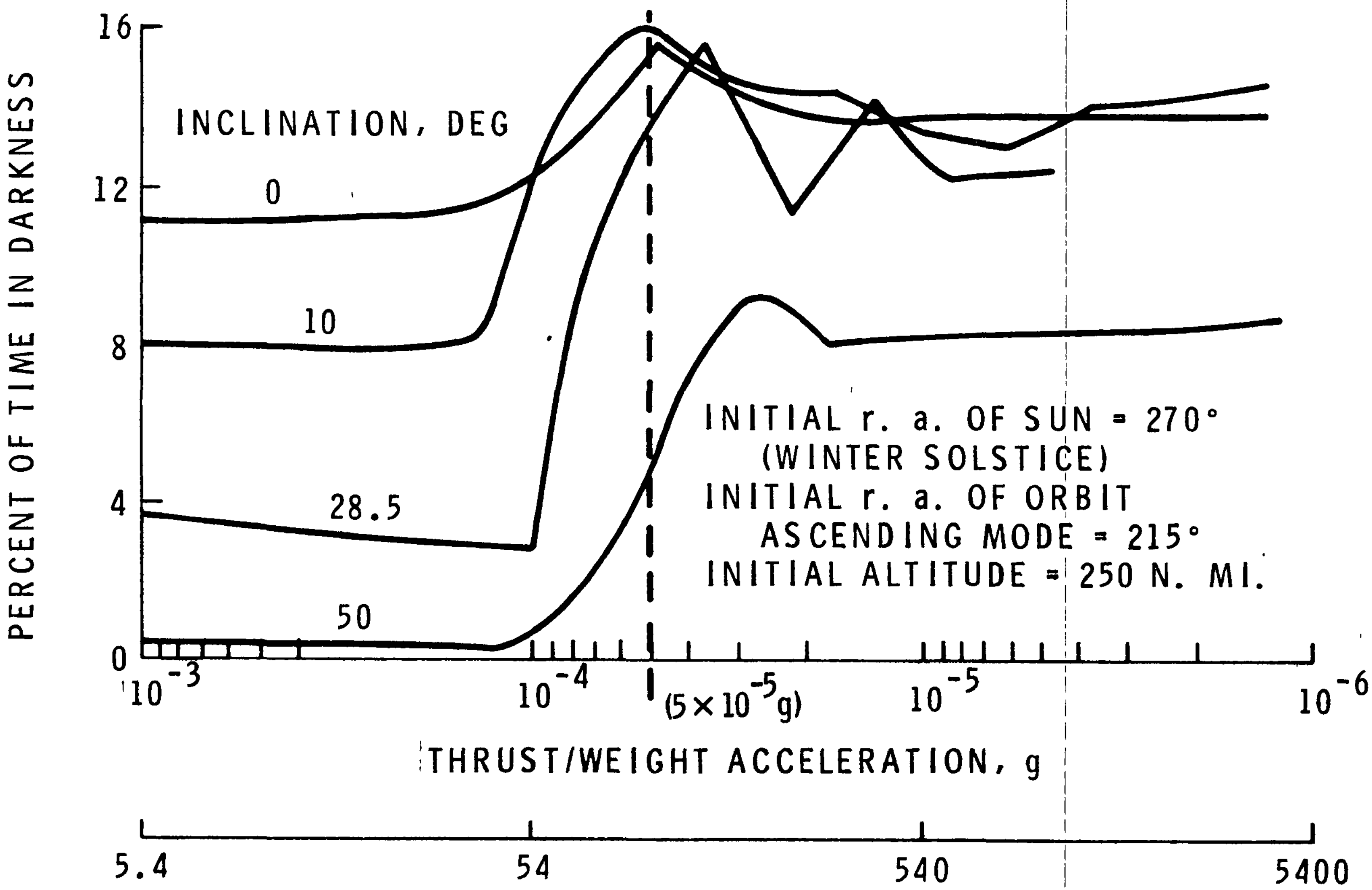

FIGURE VI-D-1

VI. SPACE TRANSPORTATION SYSTEM

E. PROPELLANT COSTS

VI-E-1. Summary and Conclusions

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A literature search, and subsequent study of an integrated space vehicle fleet provisioning system was conducted to scope the national impact and buildup commodity costs for the SPS. A detailed cross-check study was conducted to verify the technique used, and showed close correlation for the example fluid (H_2) checked.

The basic study determined the costs for LH_2, LO_2, liquid argon, propane, and RP-1 using coal, air, and water as the only raw materials. Plant investment was also found.

Study results indicated the need for a current-technology plant design to be optimized for the production of the propane (or butane) and RP-1. Specifically, it was found that;

The amount of coal to be mined and processed in order to support SPS in the peak year will amount to about 10 percent of the national output at that time.

New plant investments for SPS propellant production are about $1-1/2 B/yr throughout the SPS program.

The amount of coal required will not impact national reserves. No new technology is required to produce the subject fluids.

Detail cost data as a function of interest rate and coal price is presented and supports a small reduction in propellant costs compared to the FY-76 report for interest rates of 9 percent or less.

A major benefit of the study was to earmark those several areas where synergistic and regenerative benefits exist but require in-depth studies in themselves. For example, one area not treated at all in this study is the byproduct benefits to be derived from coal ash and slag. Among these are building blocks, gallium, arsenic, and so forth.

It is probable that other areas have been overlooked in areas such as thermodynamic heat recovery, since an older gasification process was baselined.

VI-E-2. Purpose and Requirements

This effort provided propellant cost data as a function of raw material cost, interest rate on 100 percent debt fraction, and byproduct

sales. Its purpose was to resolve discrepancies in existing cost projections by building the final cost up from basic element costs. In this way, management visibility was extended to the "study assumptions" level and bottom line costs could be redefined as parameters such as interest rate or coal cost changed or underwent redefinition.

Eight cases were provided as a baseline. These cases are given in table VI-E-1 and when taken in conjunction with table VI-E-2, provide the basis for the "snapshot-year" propellant summaries shown in table VI-E-3. For reference, vehicle configurations are given in table VI-E-4.

VI-E-3. Proposed Provisioning System

Rationale - The nation's natural gas and oil resources are projected to increase dramatically in cost, forcing a turn to coal, originally the second most economical and plentiful fossil fuel. Economic pressures will also increase the use of the lighter hydrocarbons from the "basic" methane to propane and butane. Thus, the only raw material which could rationally be considered was coal.

Likewise, the large quantities of cryogens and fuels required at the launch site more than justified the complexity and initial expense of moving the fluids by pipeline. In the quantities contemplated, even for the nominal (minimum) case, transportation by pipeline overshadows other methods, including rail, in efficiency by a large margin.

Integration of the entire provisioning system allows several synergistic and regenerative benefits which translates as a cost savings. Among these are a gasification plant which provides hydrogen (a) to be liquefied for space vehicle use, (b) to provide prime-mover power for oxygen, argon, and nitrogen liquefaction, and (c) to provide pipeline pumping power. The liquid nitrogen thus produced is used in hydrogen and propane liquefaction with residuals as a byproduct. The oxygen, produced to feed gasification of coal as well as space vehicle oxidizer, is not needed as a liquid by the coal gasification plant. Thus, its heat of vaporization is reclaimed to prechill the inlet air at the beginning of the air separation process (low temperature distillation).

Description - Figures VI-E-1 and VI-E-2 depict the proposed integrated provisioning system, both schematically and geographically. The mining, gasification, and refining of coal is taken to be in the vicinity of Casper, Wyoming due to its overall excellent quality and to large, mostly undeveloped coal fields in that region. However, bottom line costs would not be drastically affected if older, developed mines were baselined. As usual, the launch facility is assumed to remain at KSC.

Coal Gasification and Refining---The plant design for the synthesis of propellants from coal was derived from the process incorporated into a coal refinery for the production of motor gasoline in South Africa. This plant has been in operation since the mid-50's by the South African Coal, Oil, and Gas Corporation. Basically, the process involves complete gasification of coal into a mixture which is essentially composed of hydrogen and carbon monoxide. This mixture is generally referred to as synthesis gas. The synthesis gas is then converted to liquid hydrocarbons by reaction under appropriate conditions of pressure and temperature over a suitable catalyst. As in most complex chemical reactions, selectivity of the catalysts is not complete. Therefore, a variety of products are produced. Catalysts and operating conditions are thus selected to maximize the yield of the desired products.

Figure VI-E-3 presents a flow diagram for the manufacture of hydrocarbons from coal. The coal preparation step includes the normal process of crushing, drying, and removing undesirable constituents required of any gasification concept. The gasification step utilizes the Lurgi process which is the best developed and most widely used. Newer concepts now in the development stage show promise and may become favored. Some of these are the U-Gas, Hy-Gas, and CONSOL processes. In the gasification step a distillate is obtained consisting of aromatic gasoline and oils. The primary product of gasification (H_2/CO) is "shifted" as necessary with steam which increases the hydrogen content of the synthesis gas with hydrogen derived from catalytically decomposed water.

The liquefication step is a Pullman-Kellogg process labeled "SYNTHOL" which was developed from the work of Franz Fischer and Hans Tropsch of the Kaiser Wilhelm Institute dating back to 1923. This process utilizes, principally, an iron-based catalyst in powder form circulating in counterflow to the synthesis gas to produce a variety of products, largely, motor gasoline. In order to maximize the output of light hydrocarbon compounds (C_{1-4}), severe hydrocracking over suitable catalysts of the heavier gasoline molecules is required. This reaction requires a source of hydrogen which is derived from the shift conversion or from steam reforming of methane, a product of the plant.

During 1975 and 1976, the Institute of Gas Technology (IGT) conducted a study for Langley Research Center to produce aircraft fuels from coal. Also in this time period, Pullman-Kellogg (the designer of the SASOL-Synthol plant) prepared a report for the Senate Committee on Aeronautical and Space Sciences showing how the SASOL-Synthol plant could be modified to produce aviation jet fuel. These reports and telephone communication with the authors of both reports were used to establish estimates of product yields, plant size, raw materials requirements, plant costs, and product distribution of a coal refinery. Table VI-E-5 presents a summary of these estimates. Approximately 20 products

are routinely produced with the primary emphasis of the plant being upon propane. If a mix of low molecular weight hydrocarbon fuels were acceptable, the plant yield could be improved since re-refining and separation losses would be reduced.

In order to provide a basis for comparison, a column of the 1975 national production of the various products is given. It is felt that the market could absorb most of the products. Ethanol would, however, be produced at four times the 1975 production capacity for the maximum case, and unless converted to gasoline (a process is under development and showing promise to do this), the ethanol market could be glutted. Sulphur may also present a marketing problem.

Annual coal requirements are 27.5 x 10^6 and 203 x 10^6 metric tons for the minimum and maximum cases, respectively. Overall efficiency is 49 percent (Btu value of the products out/Btu value of the coal in). These estimates were derived conservatively. A more in-depth treatment of the various plant processes will likely show a considerable improvement in efficiency through better selectivity and recycling, and through a relaxing of the propane purity requirement which would improve the power output.

Cost Analysis Technique---Some idea of the fluids pricing technique can be obtained using table VI-E-6. Part I traces the required pound of LH_2 loaded aboard the vehicle backwards through the system to build up the required H_2 production at the plant. Hydrogen is taken as the example here because the analysis is the most complex due to the choice of hydrogen as a "catchall" prime-mover fuel. The byproduct stream could also supply prime-mover power but the bottom line on the propellant cost is not much affected by this choice. This is true if all the byproducts are treated as salable at the fair market price.

Part II of table VI-E-6 reverses the flow and begins with the coal mine, since part I provided the amount of coal which must be mined to ultimately load a pound of LH_2 aboard the vehicle. The left-hand column details the recurring costs, in 1976 dollars, for coal and the SNG (synthetic natural gas) credit allowable in the byproduct stream. No credit is taken for the CO_2 byproduct since the future market for large quantities of CO_2 is uncertain. To balance this uncertainty, no charge is admitted for the water required in the process. These assumptions are, and should remain, very conservative since at today's market value, 1.85 pounds of CO_2 is worth nearly 700 times as much as 2.24 gallons of water cost, even at a rather high figure for water of 7¢ per ton.

The column letter labels refer to the steps in part I and, as may be seen, no recurring charges are applicable for steps G through B since they are powered by the hydrogen already produced and capitalized in the right-hand column. The right-hand column reflects that amount of

capital needed per pound of product stream in the nominal full year of production. Part II analysis then accounts for financing that entire amount for the 30-year plant (and SPS program) life to arrive at fluid costs per pound as a function of interest rate.

Cost Curves---Part IV of table VI-E-6 results in the data plotted in figures VI-E-4 through VI-E-11. In each case, three coal costs were taken. Coal at $5.50/metric ton would reflect a situation where the coal fields were already owned by the government and captive to the SPS (or other government program) and therefore insulated from the market. That is, charges are for labor only since plant capitalization has already been accounted. The $17/metric ton is a good current average cost for coal purchased from a private operator while $30/metric ton is a projected next-decade cost and not in 1976 dollars. These amounts are conservative by, at least, the plant capitalization penalty.

Each curve on each cost data figure is a double curve and represents a 5 percent spread to account for operating labor in the plants and on the pipelines. It is seen that the interest rate is the dominant parameter over coal and labor cost and even over whether a credit is allowed for the byproduct stream. Figures VI-E-5, VI-E-9, and VI-E-11 depict a situation where no credits are allowed. This variation is provided in lieu of a lengthy and uncertain market forecast in order to bracket the best and worst case for propellant cost. In all cases, 100 percent debt fraction and no profit operations were assumed.

The oxygen and argon curves are of a unique nature in that, as a benefit of baselining an integrated provisioning system, they are insensitive to coal costs and do not have a significant byproduct stream credit possibility. This situation arises from the fact that the hydrogen cost includes the cost of liquid nitrogen production to support its liquefaction for use on the spacecraft. As a "byproduct," enough liquid oxygen and liquid argon are distilled (for the maximum case) to meet the spacecraft needs.

No credits are allowed for liquid nitrogen residuals since its optimum use should be the subject of another lengthy study. It would be used to liquefy propane in Wyoming and prechill inlet air to the KSC separation plant. Additional large quantities are available due to its high mass fraction in the atmosphere, and are shown schematically on figure VI-E-3 as a byproduct. It could, however, be used to air-condition the blockhouses at KSC.

VI-E-4. National Impact

The quantities of coal required to support the SPS program in a peak year would, if needed now, constitute a large percentage of the 1976 production (about 2/3 of it). However, even conservative projections of coal production during the rest of this century indicate a minimal impact. This is certainly evident when 63 percent will be used in 1980 for the production of electricity in conventional plants. Figure VI-E-12 shows the SPS impact in 1995-2000 A.D. very dramatically.

Table VI-E-7 gives some actual past values of coal production in the U.S. as well as some estimates of future production.

In conclusion, table VI-E-8 is presented to bracket the investment to be made to provide the physical plant for the SPS provisioning system. It is apparent throughout, and here especially, that the three additional SPS constructed per year for the maximum case represent significant additional expenditures. It should, however, be a straightforward exercise to design a modern coal gasification plant and refinery that is optimum for SPS needs. The size (and byproduct stream) of the coal refinery would thus be reduced and bring the capital investment of 4 to 29 billion dollars into line.

- ALL CONFIGURATIONS ARE TRUSS-TYPE CONFIGURATIONS -

CASE I	GEO ASSEMBLY. CONSTRUCT 4 SPS AND REPAIR 112 SPS IN ONE YEAR. USE NOMINAL VALUES. CIRCA 2010-2025.
CASE II	GEO ASSEMBLY AS ABOVE, CASE I. USE MAXIMUM VALUES.
CASE III	GEO ASSEMBLY. CONSTRUCT 7 SPS AND REPAIR 112 SPS IN ONE YEAR. USE NOMINAL VALUES. CIRCA 2022-2025.
CASE IV	GEO ASSEMBLY AS ABOVE, CASE III. USE MAXIMUM VALUES.
CASE V	LEO ASSEMBLY. CONSTRUCT 4 SPS AND REPAIR 112 SPS IN ONE YEAR. USE NOMINAL VALUES. CIRCA 2010-2025.
CASE VI	LEO ASSEMBLY AS ABOVE, CASE V. USE MAXIMUM VALUES.
CASE VII	LEO ASSEMBLY. CONSTRUCT 7 SPS AND REPAIR 112 SPS IN ONE YEAR. USE NOMINAL VALUES. CIRCA 2022-2025.
CASE VIII	LEO ASSEMBLY AS ABOVE, CASE VII. USE MAXIMUM VALUES.

Table VI-E-1. SPS IMPLEMENTATION CASES

VEHICLE FLIGHTS

	CASE I	II	III	IV	V	VI	VII	VIII
HLLV FLIGHTS	2388	5616	3786	8904	1484	3645	2345	5764
$COTV_G$ FLIGHTS	1901	2765	3015	4386	—	—	—	—
$COTV_L$ FLIGHTS	—	—	—	—	470	687	742	1086
PLV FLIGHTS	176	234	266	354	206	264	319	409
$POTV_G$ FLIGHTS	32	34	47	50	—	—	—	—
$POTV_L$ FLIGHTS	—	—	—	—	57	57	73	73

Table VI-E-2. VEHICLE FLIGHTS

CASE NO.	I	II	III	IV	V	VI	VII	VIII
HYDROGEN								
NOM.	0.77×10^6	1.73×10^6	1.25×10^6	2.74×10^6	0.46×10^6	1.07×10^6	0.73×10^6	1.69×10^6
MAX.	1.47×10^6	3.35×10^6	2.37×10^6	5.3×10^6	0.89×10^6	2.11×10^6	1.41×10^6	3.33×10^6
OXYGEN								
NOM.	20.7×10^6	48.73×10^6	33.48×10^6	77.24×10^6	13.04×10^6	31.42×10^6	20.59×10^6	49.68×10^6
MAX.	21.17×10^6	49.82×10^6	34.24×10^6	78.96×10^6	13.34×10^6	32.13×10^6	21.07×10^6	50.80×10^6
ARGON								
NOM.	5.3×10^3	5.64×10^3	7.79×10^3	8.29×10^3	77.9×10^3	113.8×10^3	122.99×10^6	180.02×10^6
MAX.	6.62×10^3	7.03×10^3	9.72×10^3	10.34×10^3	97.18×10^3	142.0×10^3	153.42×10^6	224.5×10^6
PROPANE								
NOM.	5.35×10^6	12.57×10^6	8.48×10^6	19.93×10^6	3.32×10^6	8.16×10^6	5.25×10^6	12.9×10^6
MAX.	6.22×10^6	14.62×10^6	9.86×10^6	23.19×10^6	3.86×10^6	9.49×10^6	6.11×10^6	15.01×10^6
RP-1								
NOM.=MAX.	71.28×10^3	94.76×10^3	107.7×10^3	143.4×10^3	83.42×10^3	106.91×10^3	129.19×10^3	165.6×10^3

Table VI-E-3. FUELS AND PROPELLANTS REQUIREMENTS SUMMARY
-METRIC TONS-

GLOSSARY AND PROPELLANT APPLICATIONS

HLLV - HEAVY LIFT LAUNCH VEHICLE

NOMINAL - 2 STAGE BALLISTIC

- o 1ST STAGE - LO_2 AND PROPANE
- o 2ND STAGE - LO_2 AND LH_2

MAXIMUM - 2 STAGE WINGED

- o 1ST STAGE - LO_2 AND PROPANE
- o 2ND STAGE - LO_2 AND LH_2

$COTV_G$ - CARGO ORBITAL TRANSFER VEHICLE, GEOSYNCHRONOUS EARTH ORBIT (GEO) ASSEMBLY OF THE SOLAR POWER SATELLITE (SPS)

- o 2-1/2 STAGE - LO_2 AND LH_2 ALL STAGES

$COTV_L$ - CARGO ORBITAL TRANSFER VEHICLE, LOW EARTH ORBIT (LEO) ASSEMBLY OF THE SOLAR POWER SATELLITE

- o COMBINED ELECTRIC AND CHEMICAL - LO_2, LH_2, AND ARGON

Table VI-E-4. GLOSSARY AND PROPELLANT APPLICATIONS

GLOSSARY AND PROPELLANT APPLICATIONS (CONTINUED)

PLV - PERSONNEL LAUNCH VEHICLE - SAME FOR GEO AND LEO ASSEMBLY TASKS

- o EXTERNAL TANK - LO_2 AND LH_2
- o BOOSTER - LO_2 AND RP-1

$POTV_G$ - PERSONNEL ORBITAL TRANSFER VEHICLE - GEO ASSEMBLY TASKS

- o COMBINED ELECTRIC AND CHEMICAL - LO_2, LH_2, AND ARGON

$POTV_L$ - PERSONNEL ORBITAL TRANSFER VEHICLE - LEO ASSEMBLY TASKS

- o COMMON STAGE LO_2 AND LH_2

GEO - GEOSYNCHRONOUS EARTH ORBIT

LEO - LOW EARTH ORBIT

Table VI-E-4

PRODUCT	MIN. CASE	MAX. CASE	1975 NAT'L PRODUCT
OXYGENATED CHEMICALS			
ACETALDEHYDE	32.00	236.76	1500.00
METHANOL	8.50	62.86	5660.00
ACETONE	98.75	730.75	2015.00
METHYL ETHYL KETONE	36.54	270.40	5056.00
ETHANOL	1086.50	8040.10	2120.00
i-BUTANOL	33.34	246.72	115.00
n-BUTANOL	80.20	593.48	551.00
HEAVY ALCOHOLS	116.55	862.47	-----
ACETIC ACID	130.50	965.70	2265.00
PROPIONIC ACID	41.08	303.99	-----
HIGHER ACIDS	28.44	210.46	-----
OLEFINS			
ETHYLENE	396.35	2932.99	23,500.00
BUTENE/BUTANE	693.50	5131.90	
SULFUR	1925.00	14,245.00	23,600.00
BTX, GASOLINE, OILS	2696.80	19,956.32	24,290.00 (BTX)
SNG	900.00	6660.00	-----
RP-1	42.50	314.50	-----
PROPANE	6912.95	51,155.83	-----
TOTAL PLANT OUTPUT	15,309.35	113,289.19	NA
COAL FLOW (M.T./YR.)	27.45×10^6	203.1×10^6	NA

Table VI-E-5. COAL REFINERY PRODUCT DISTRIBUTION

-LBS./YR. X 10^6-

-HYDROGEN-

PART I - TRACE 1 LB. OF H_2 BACKWARDS THROUGH THE SUPPLY SYSTEM

A. PUMP 1 LB. OF LH_2 ABOARD THE VEHICLE.

B. STORE 1.05 LBS. IN A DEWAR FOR 2 DAYS.

C. LIQUEFY 1.05 LBS. OF GH_2 - USE 0.259 LBS. GH_2 - POWER.

D. LIQUEFY 1.124 LBS. OF GN_2 - USE 0.1345 LBS. GH_2 - POWER.

E. PUMP

1.050	
.259	
.1345	
1.4435	LBS. OF GH_2 ON-SITE AT KSC.

F. PUT 1.64125 LBS. OF GH_2 INTO PIPELINE IN WYOMING. USE 0.1977 LBS. OF GH_2 TO PROVIDE PUMPING POWER.

G. CRACK 8.106 LBS. OF O_2 OUT OF THE ATMOSPHERE. USE 0.7705 LBS. OF GH_2 FOR POWER.

H. PRODUCE

1.64125	
0.7705	
2.412	LBS. OF H_2 IN GASIFIER PLANT.

I. CONSUME 19.899 LB. OF COAL, PRODUCE BYPRODUCTS.

J. MINE 20.9 LBS. OF COAL, USE 1.001 LBS. OF COAL FOR POWER.

EXAMPLE

Table VI-E-6. COST ANALYSIS TECHNIQUE

PART II - COST EACH STEP IN THE TRACE

PART II - COST EACH STEP IN THE TRACE

	RECURRING	CAPITALIZATION RATIO
J.	PAY FOR 20.9 LBS OF COAL AT: \$5.50/M.T. = \$0.052 \$17.00/M.T. = \$0.16 \$30.00/M.T. = \$0.27	\$0.0003703/LB. × 20.9 LBS. = \$0.007739
I. + H.	PRODUCE: 1.85 LBS. CO_2 - NO CREDIT 4.91 LBS. SNG - \$0.1909 2.42 LBS H_2 USE 2.24 GALS. H_2O - NO CHARGE	\$0.024358/LB. × 20.9 LBS. = \$0.509
G.		\$0.0009/LB. × 8.106 LBS., O_2 = \$0.00733
F. + E.		\$0.0197 × 1.64125 LBS. OF H_2 = \$0.032
D. + C.		\$0.0796 × 1.124 LBS, N_2 = \$0.0895 \$0.13828 × 1.05 LBS, H_2 = \$0.1452
B.		\$0.533/LB./YR. × $\frac{2 \text{ DAYS}}{365 \text{ DAYS}}$ × 1.00 LB = \$0.00292

PART III - FINANCE RIGHT-HAND COLUMN FOR 30 YRS. TO OBTAIN CAPITALIZATION ELEMENT OF COST OF LH_2 LOADED. ADD YEARLY OPERATING AND MATERIALS PER LB.

PART IV - PLOT COST AS F(INTEREST RATE) + CORRECT FOR LABOR CHARGES.

Table VI-E-6 Concluded

COAL PRODUCTION IN THE U.S.-

1947	—	OVER 630 MILLION TONS
1954	—	LESS THAN 400 MILLION TONS
1967	—	OVER 550 MILLION TONS (UTILITIES USED 290 MILLION TONS)
1973	—	OVER 568 MILLION TONS
1980 PREDICTED*	—	718 MILLION TONS (UTILITIES TO USE AS MUCH AS 450 MILLION TONS)
2000 PREDICTED*	—	AS MUCH AS 2.6 BILLION TONS

ESTIMATED RESERVES IN THE U.S.- RECOVERABLE

3210 BILLION TONS* - HALF ARE KNOWN

SPS PROJECTED REQUIREMENTS-

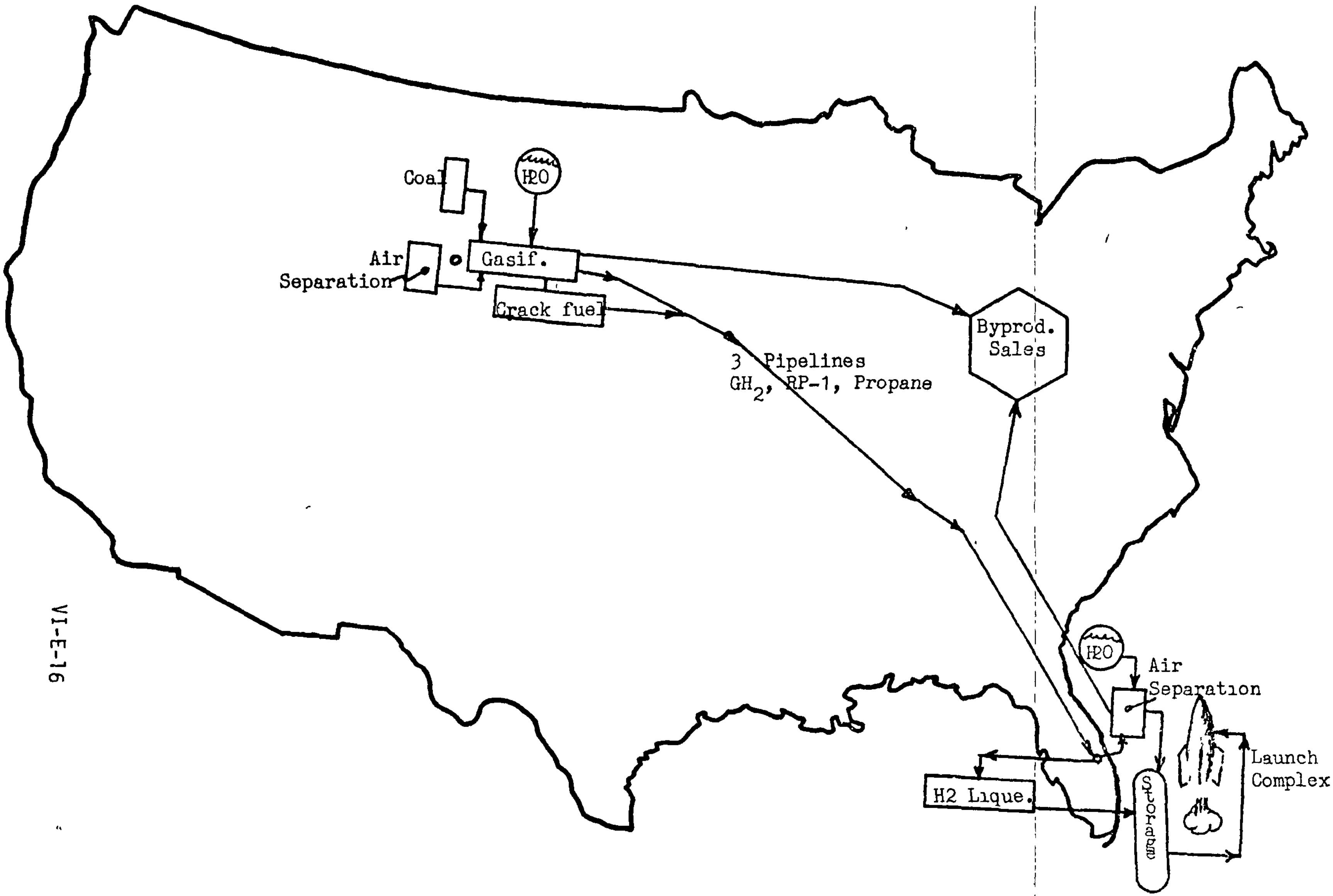
NOMINAL YEAR: 83.3 MILLION TONS SEE CASE V

MAXIMUM YEAR: 472.5 MILLION TONS SEE CASE IV

* COLORADO SCHOOL OF MINES SYMPOSIUM

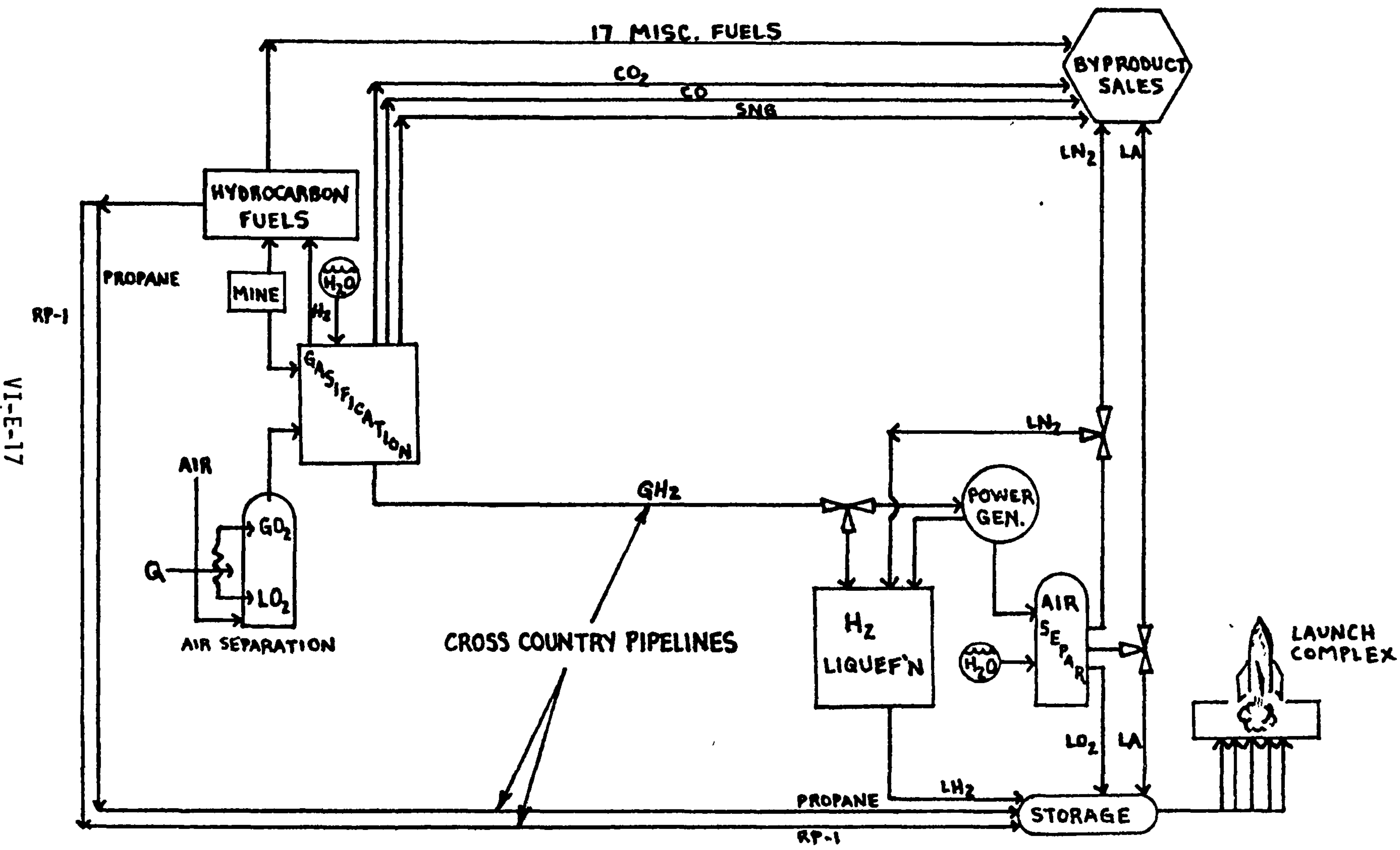
Table VI-E-7. COAL REQUIREMENTS COMPARISON

-U. S. TONS-



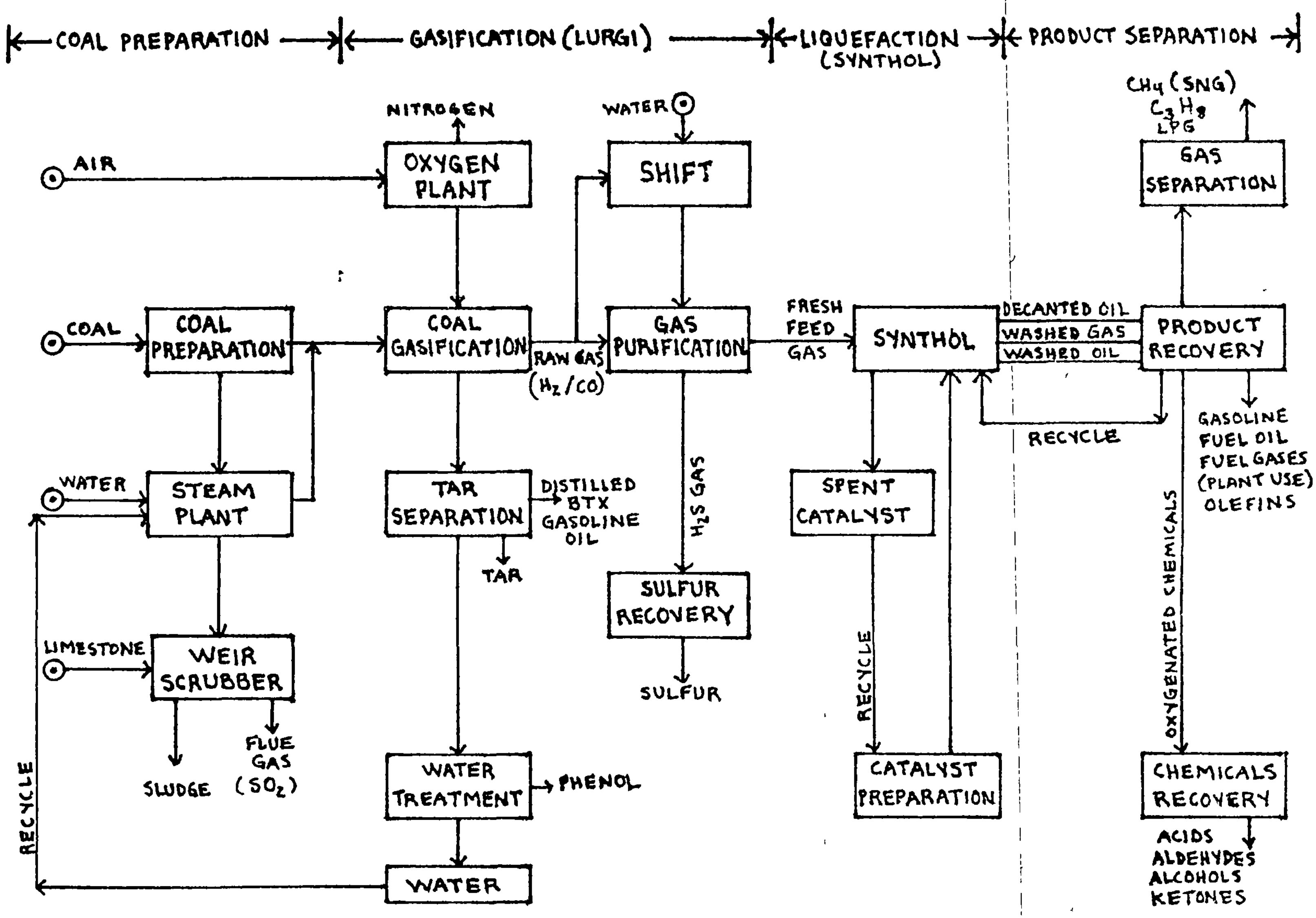
Coal
H2O
Air
Separation
Gasif.
Crack fuel
3 Pipelines
GH2, RP-1, Propane
Byprod.
Sales
H2O
Air
Separation
H2 Lique.
Storage
Launch
Complex

Figure VI-E-1



17 MISC. FUELS
CO_2
CO
SNG
BYPRODUCT SALES
LN_2
LA
HYDROCARBON FUELS
PROPANE
RP-1
MINE
H_2O
H_2
GASIFICATION
AIR
GO_2
Q
LO_2
AIR SEPARATION
GH_2
CROSS COUNTRY PIPELINES
LN_2
POWER GEN.
H_2 LIQUEF'N
AIR SEPAR
H_2O
LAUNCH COMPLEX
LO_2
LA
LH_2
PROPANE
STORAGE
RP-1

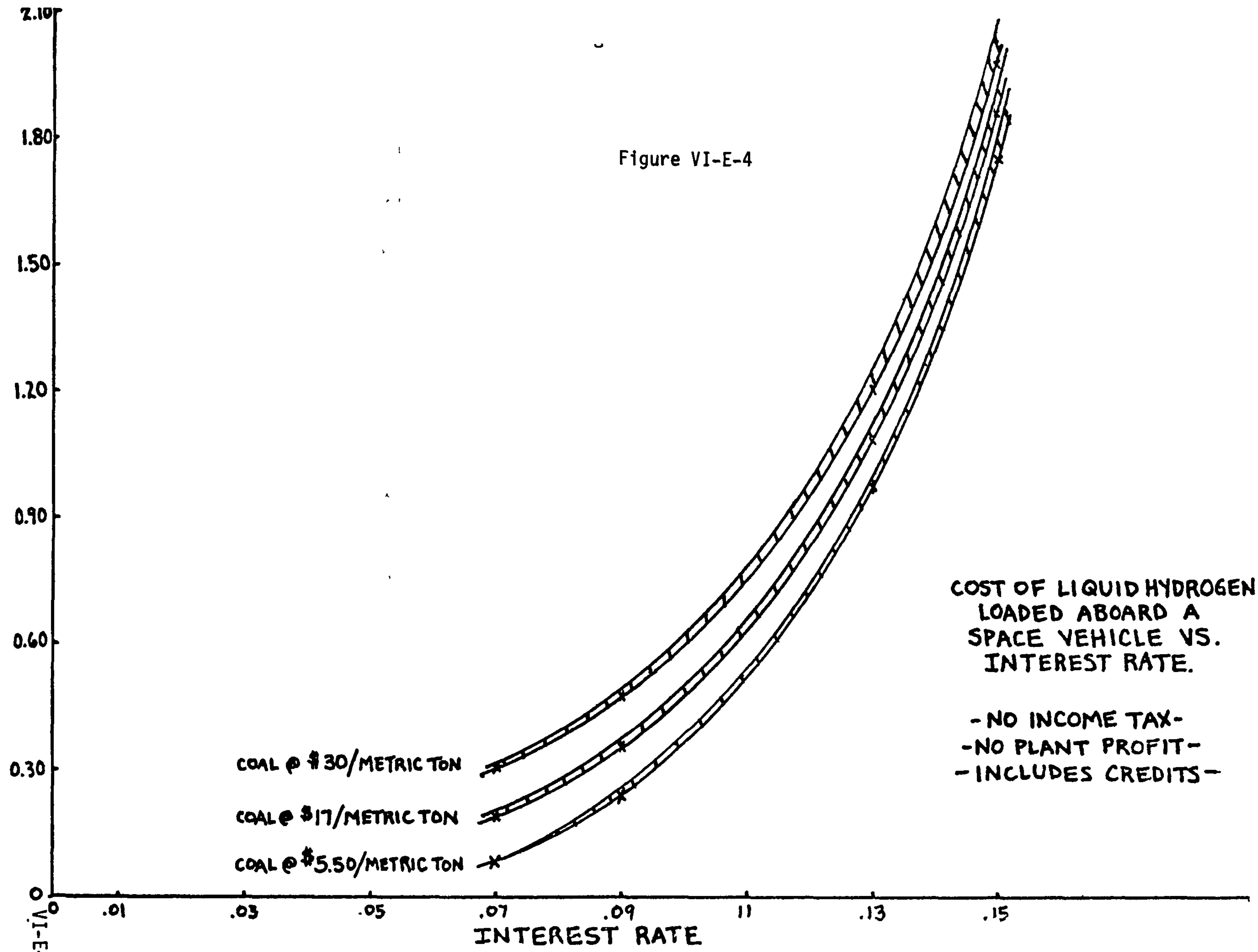
Figure VI-E-2



FLOW DIAGRAM FOR MANUFACTURE OF HYDROCARBONS FROM COAL BY THE SASOL-SYNTHOL PROCESS

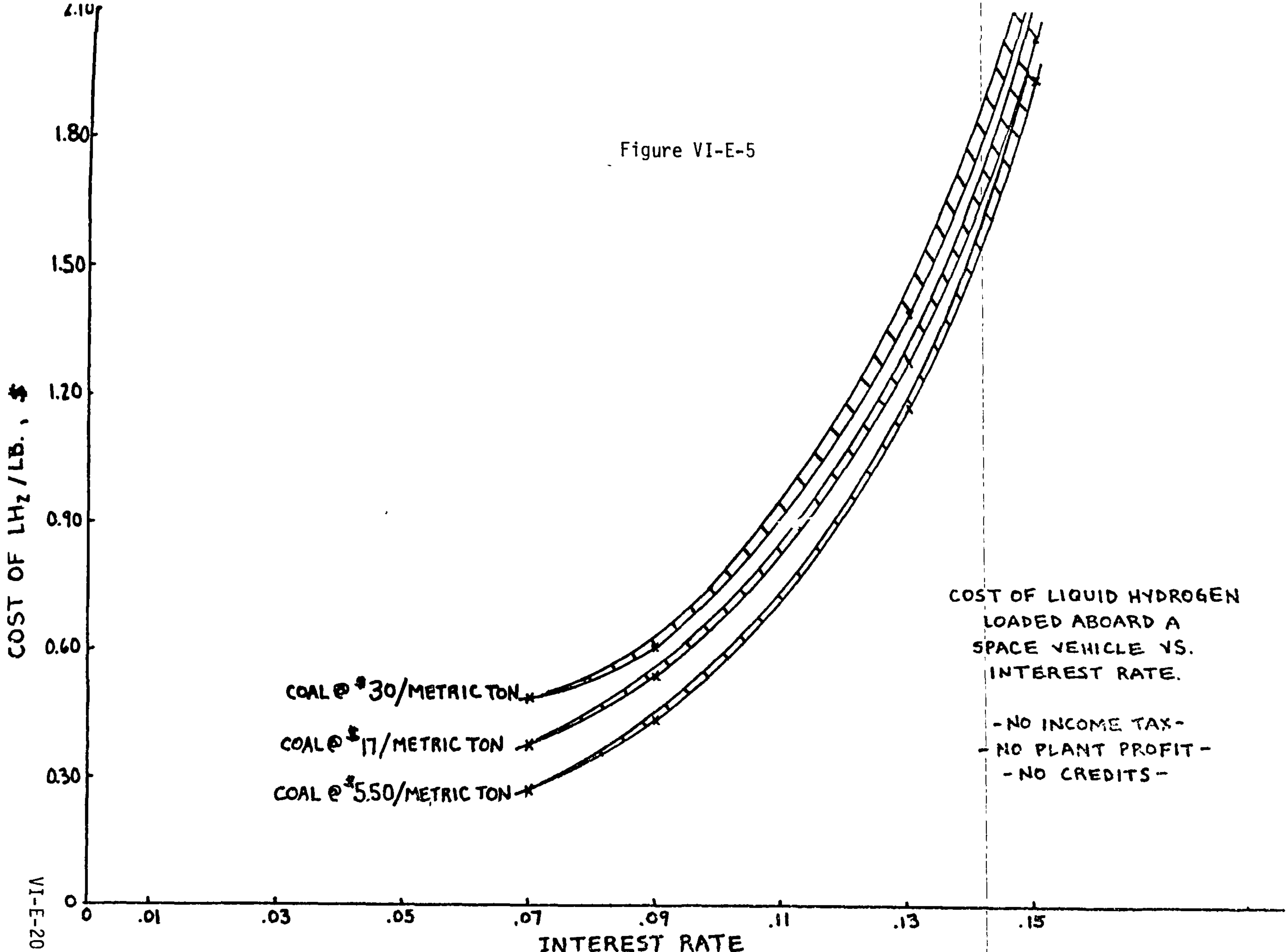
Figure VI-E-3

Figure VI-E-4



COST OF LIQUID HYDROGEN LOADED ABOARD A SPACE VEHICLE VS. INTEREST RATE.
-NO INCOME TAX-
-NO PLANT PROFIT-
-INCLUDES CREDITS-
COAL @ $30/METRIC TON
COAL @ $17/METRIC TON
COAL @ $5.50/METRIC TON
2.10
1.80
1.50
1.20
0.90
0.60
0.30
0
0
.01
.03
.05
.07
.09
11
.13
.15
INTEREST RATE

Figure VI-E-5



2.10
1.80
1.50
1.20
0.90
0.60
0.30
0
COST OF LH_2/LB., $
COAL @ $30/METRIC TON
COAL @ $17/METRIC TON
COAL @ $5.50/METRIC TON
COST OF LIQUID HYDROGEN LOADED ABOARD A SPACE VEHICLE VS. INTEREST RATE.
- NO INCOME TAX -
- NO PLANT PROFIT -
- NO CREDITS -
0
.01
.03
.05
.07
.09
.11
.13
.15
INTEREST RATE

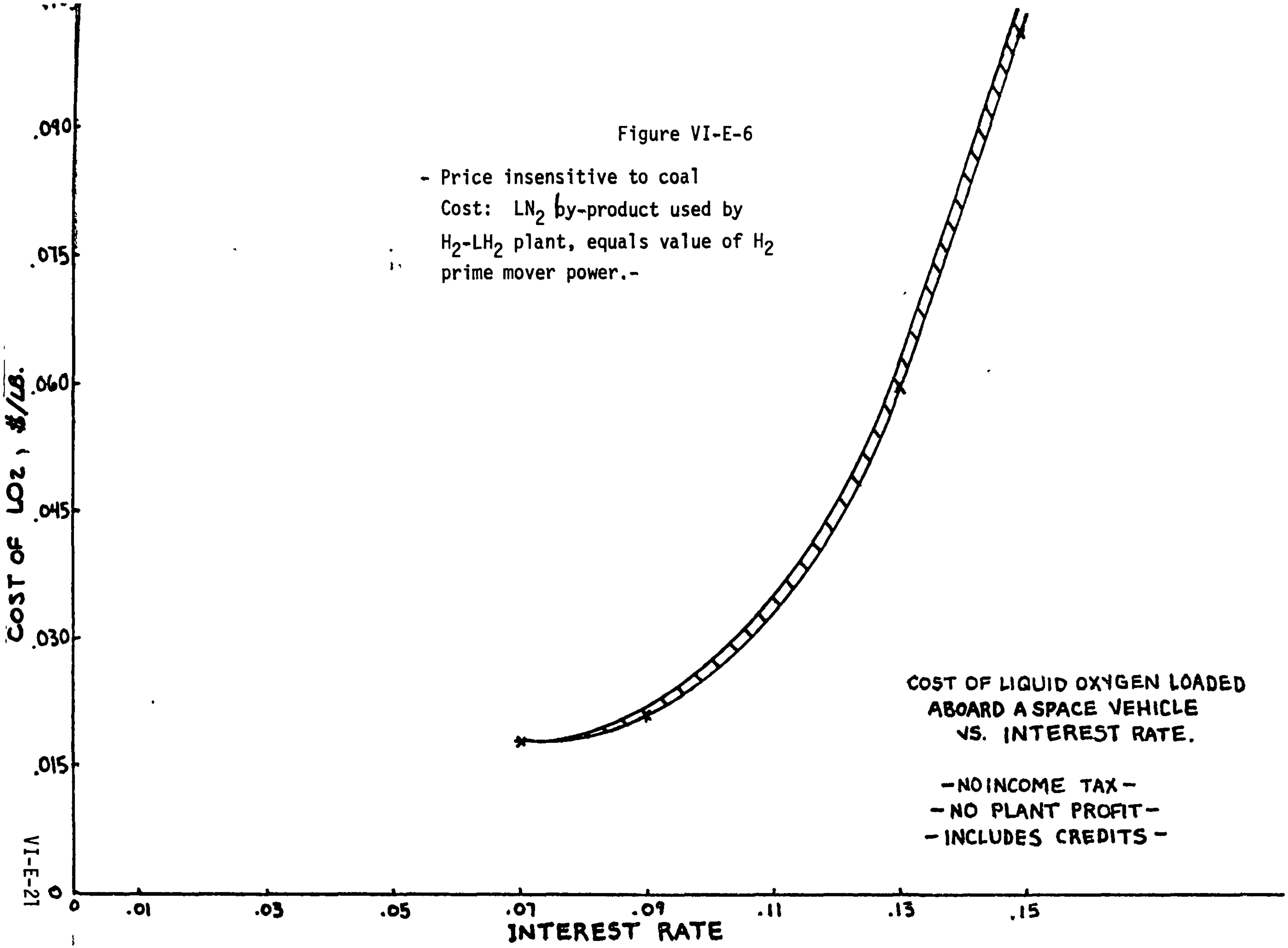


Figure VI-E-6

- Price insensitive to coal
Cost: LN_2 by-product used by H_2-LH_2 plant, equals value of H_2 prime mover power.-

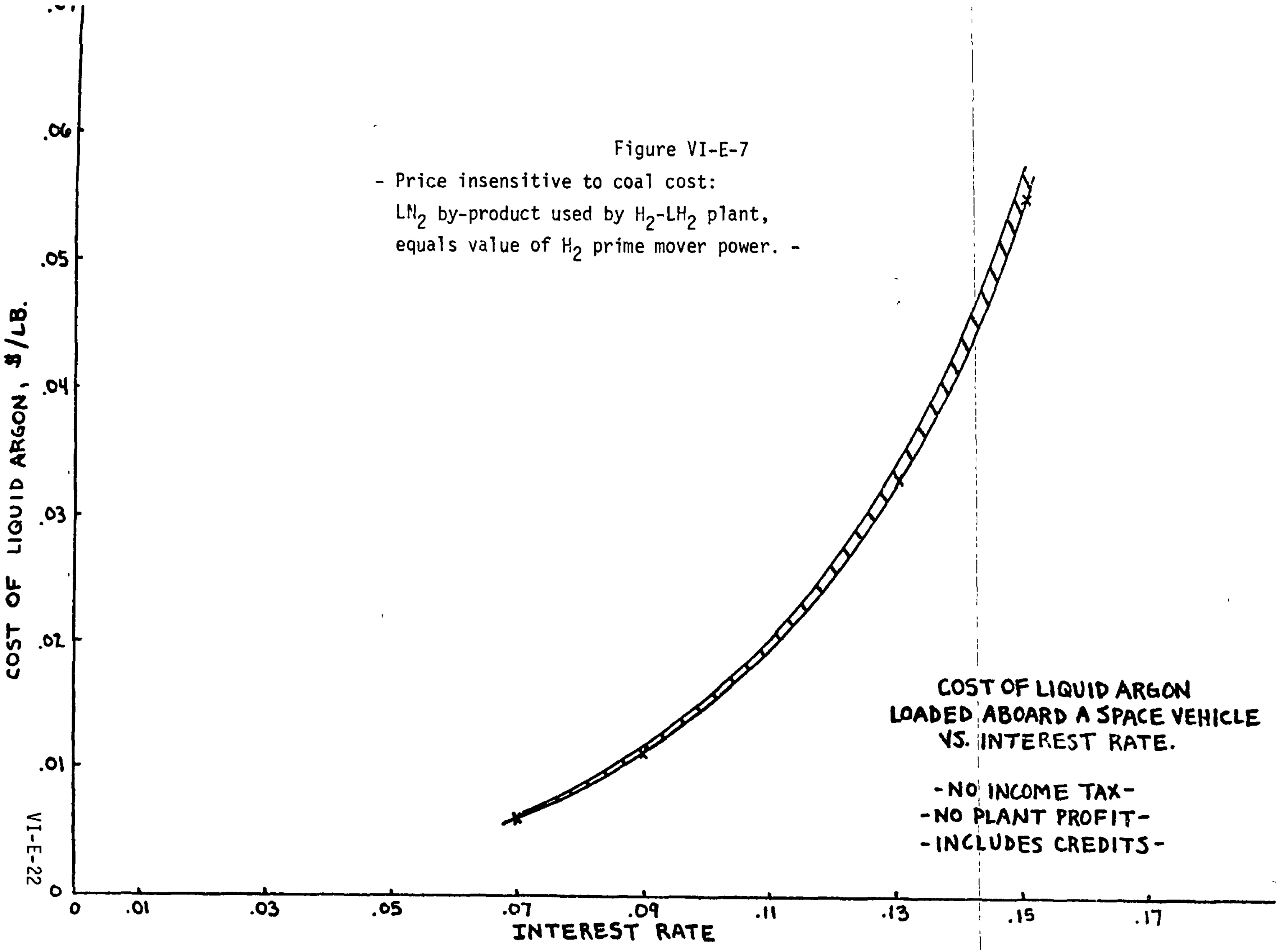


Figure VI-E-7
- Price insensitive to coal cost:
LN_2 by-product used by H_2-LH_2 plant,
equals value of H_2 prime mover power. -
COST OF LIQUID ARGON
LOADED ABOARD A SPACE VEHICLE
VS. INTEREST RATE.
-NO INCOME TAX-
-NO PLANT PROFIT-
-INCLUDES CREDITS-
COST OF LIQUID ARGON, $/LB.
.06
.05
.04
.03
.02
.01
0
0
.01
.03
.05
.07
.09
.11
.13
.15
.17
INTEREST RATE

Figure VI-E-8

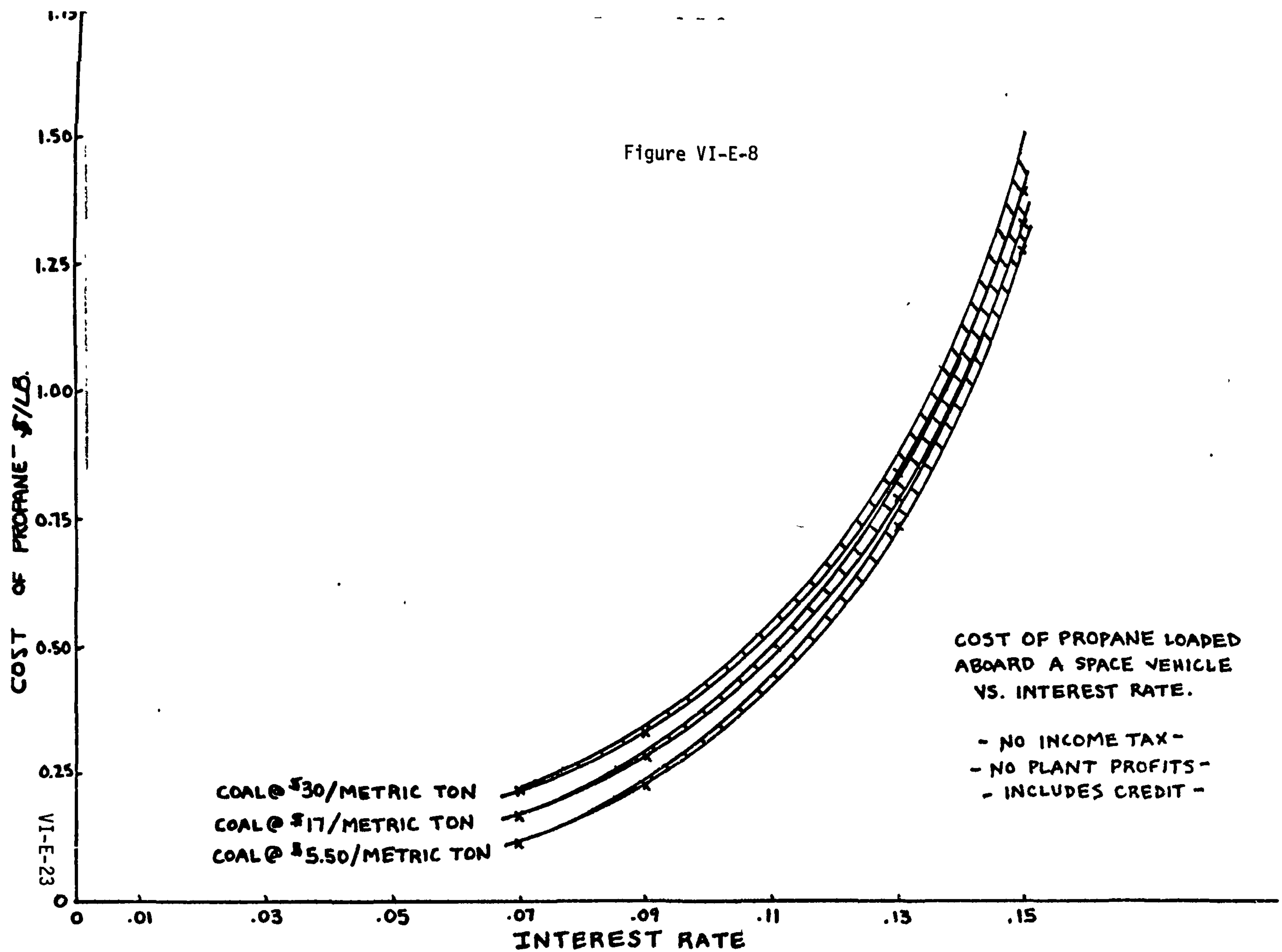

COST OF PROPANE LOADED ABOARD A SPACE VEHICLE VS. INTEREST RATE.
- NO INCOME TAX -
- NO PLANT PROFITS -
- INCLUDES CREDIT -
COAL @ $30/METRIC TON
COAL @ $17/METRIC TON
COAL @ $5.50/METRIC TON
COST OF PROPANE - $/LB.
1.50
1.25
1.00
0.75
0.50
0.25
0
INTEREST RATE
0
.01
.03
.05
.07
.09
.11
.13
.15

Figure VI-E-9

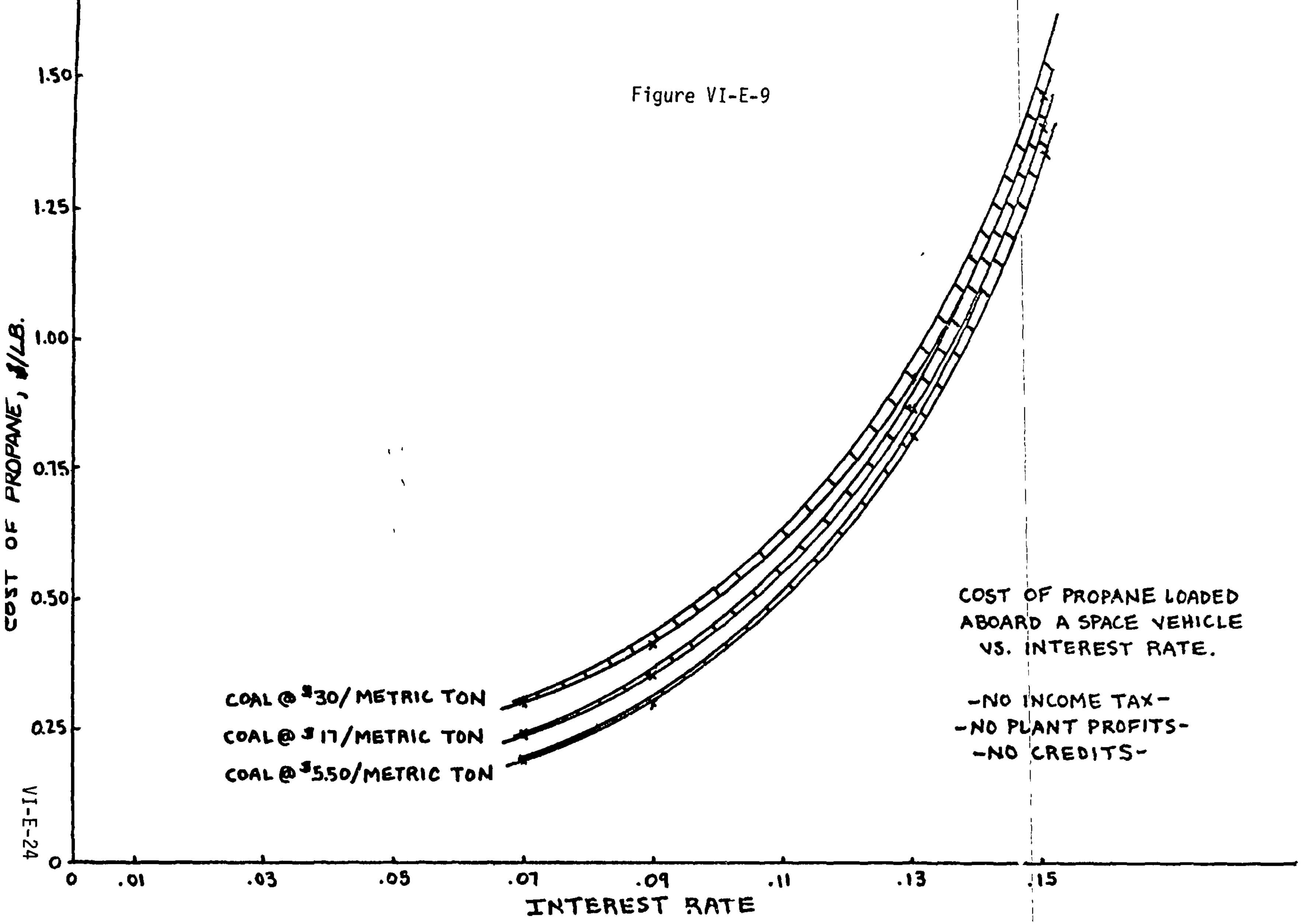
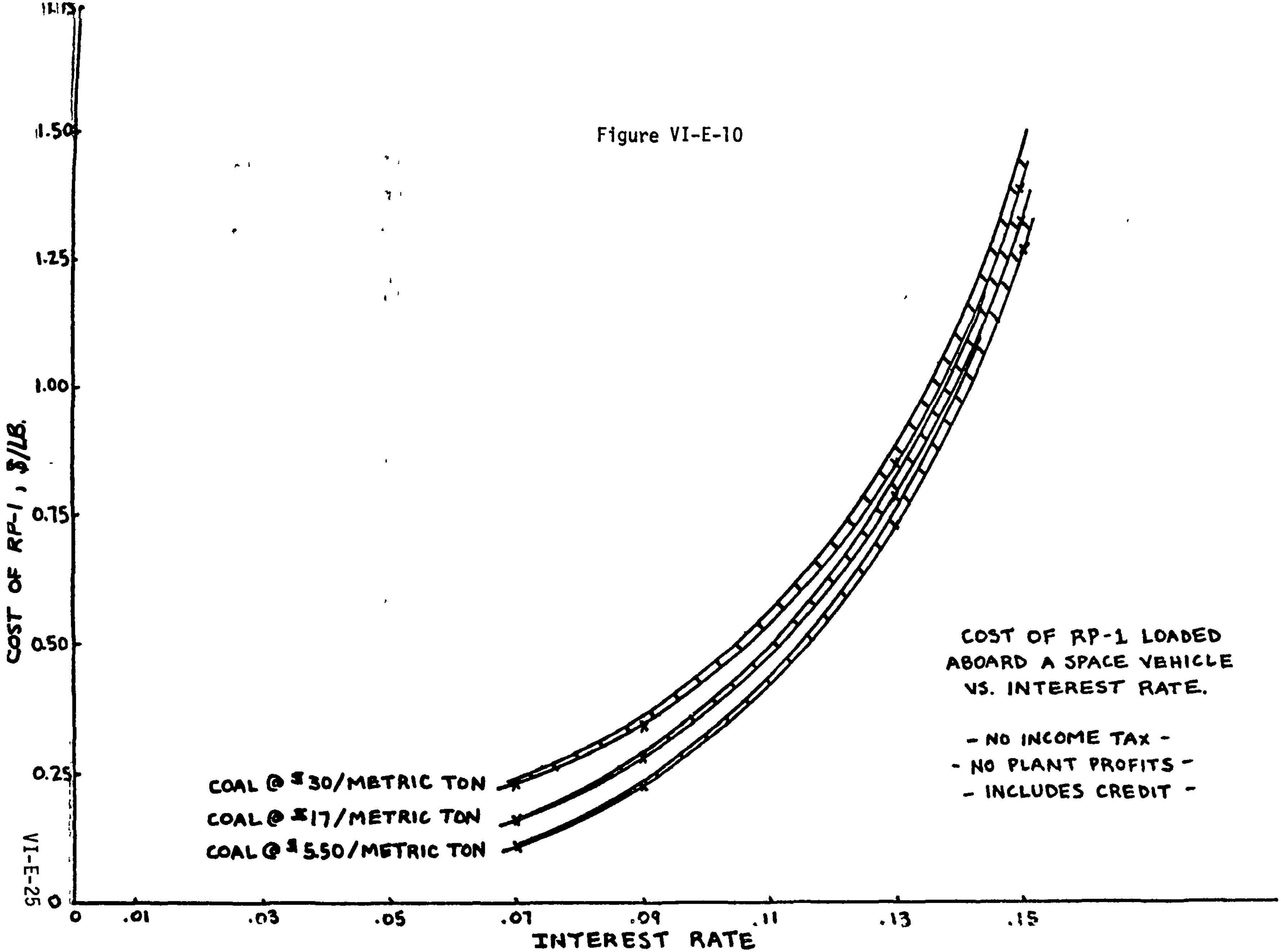

COST OF PROPANE, $/LB.
1.50
1.25
1.00
0.75
0.50
0.25
0
.01
.03
.05
.07
.09
.11
.13
.15
INTEREST RATE
COAL @ $30/METRIC TON
COAL @ $17/METRIC TON
COAL @ $5.50/METRIC TON
COST OF PROPANE LOADED
ABOARD A SPACE VEHICLE
VS. INTEREST RATE.
-NO INCOME TAX-
-NO PLANT PROFITS-
-NO CREDITS-

Figure VI-E-10



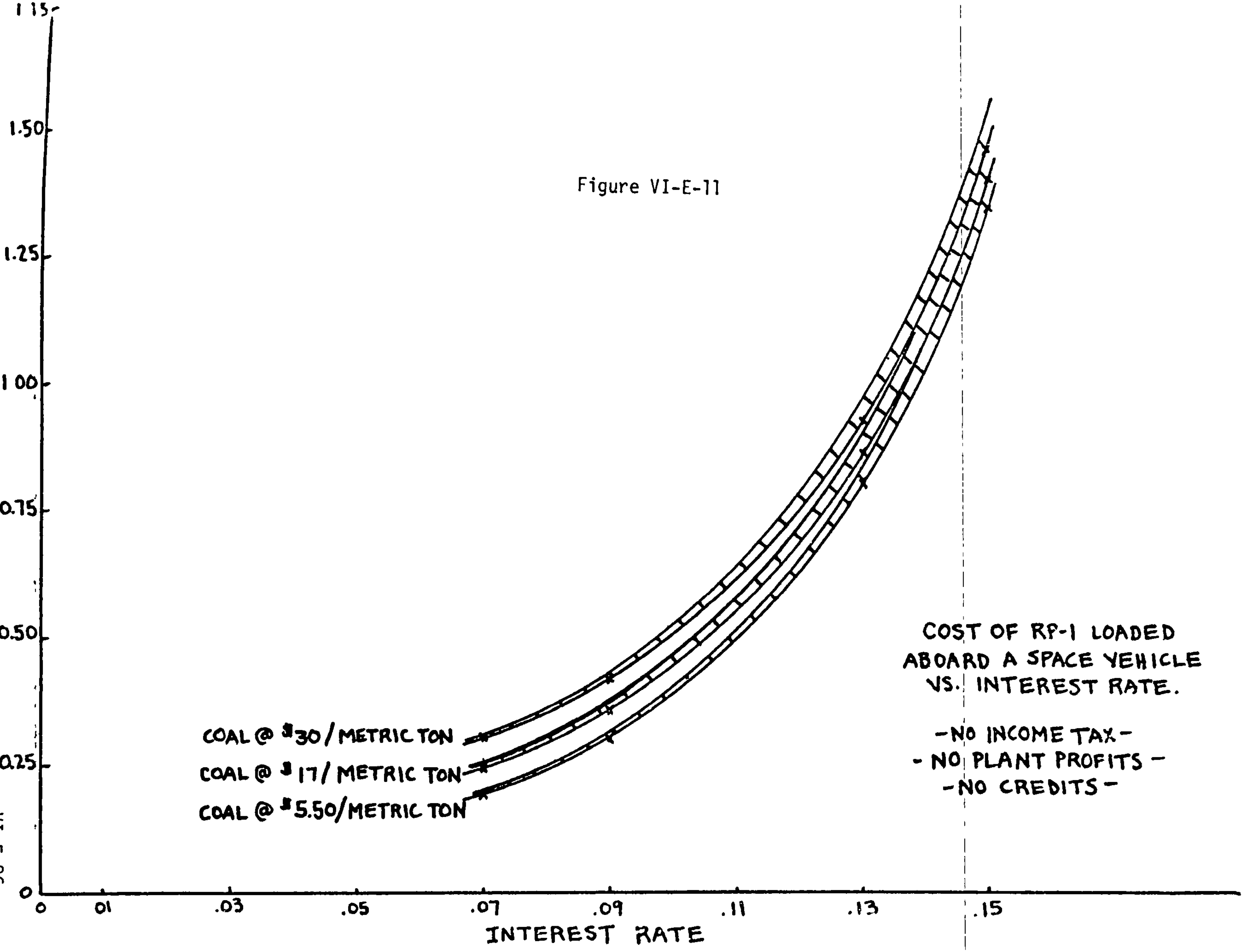


Figure VI-E-11

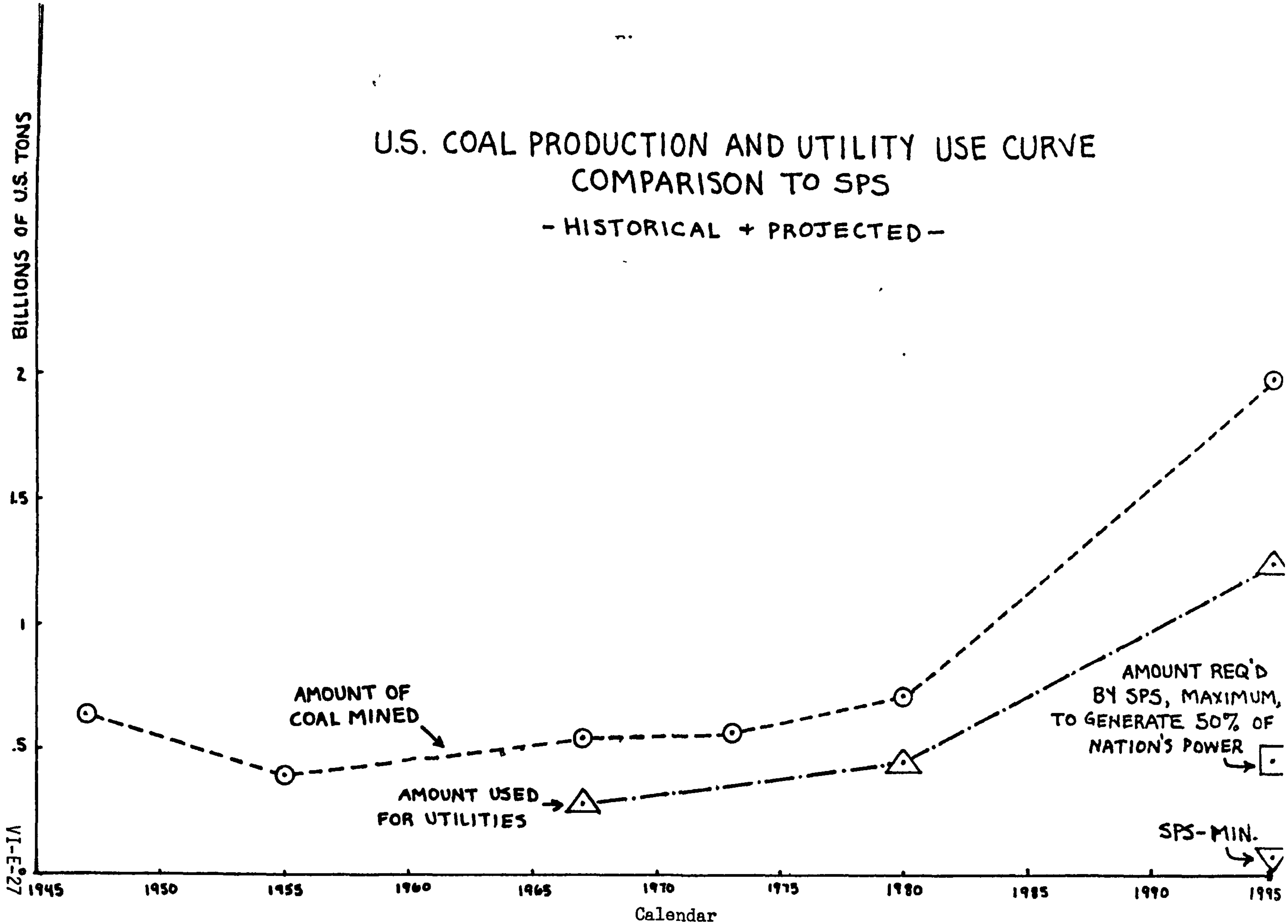


Figure VI-E-12

VI. SPACE TRANSPORTATION SYSTEM

F. SPS Transportation Scenario Synthesis

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Future Programs Office

Introduction

To understand the space transportation fleet traffic and implications thereof, a space transportation scenario was developodd as associated with the SPS implementation scenario for the FY 76 study. For FY 77, two SPS placement schedules (Scenario A' and C') are utilized to evaluate the effects of increasing the annual maximum SPS implementation rate from two to five over a 16-year period. Figure VI-F-1 presents these SPS placement schedules. In addition, annual repair of the on-orbit operational SPS units represents a space transportation requirement above the construction-related requirement. The annual repair payload mass has been estimated at 1% of the on-orbit operational SPS mass. For the FY 77 study, the space transportation fleet design was assumed to have a useful life of 16 years through the year 2010 (as compared to the FY 76 study groundrule of 30 year fleet design life). This assumption is based on the hypothesis that advancement in technology and operations will dictate a cost effective redesign of the fleet for the last half of the SPS program.

The operational requirements of the transportation system were considered for two SPS construction options (truss/GEO and truss/LEO) in order to scope the transportation costs and other parameters for the baseline scenario. Maximum, nominal and minimum estimates of characteristics were made for each option by using all worst case estimates of characteristics for maximum, characteristics judged "most likely" for nominal, and optimistic estimates of characteristics for minimum.

The space transportation fleet is characterized by four vehicles:

a. Heavy Lift Launch Vehicle (HLLV) - unmanned launches of all cargo to LEO.

b. Cargo Orbital Transfer Vehicle (COTV) - LEO to GEO transfer of all cargo.

c. Personnel Orbital Transfer Vehicle (POTV) - LEO to GEO and return transfer of all personnel and optional high priority cargo to LEO.

d. Personnel and Priority Cargo Launch Vehicle (PLV) - manned launches of all personnel and optional high priority cargo to LEO.

The space transportation scenario logic involving operational aspects of the SPS and characteristics of the space transportation fleet

was developed by the Future Programs Office for the FY 76 study and updated for FY 77. The effort involved a HP-9810A computer program with typewriter output so that yearly and total SPS program space transportation traffic models and sensitivities with associated costs could be derived efficiently as corresponding scenario data inputs evolved.

Launch Site Considerations

As in FY 76, a 28.5° latitude due east launch was assumed for the HLLV's, requiring the OTV's to make the plane change for the equatorial orbit. This is a conservative assumption for performance, since an equatorial launch site offers the advantages of increased Earth rate, a slight increase in altitude because of the Earth's oblatness and, most importantly, the elimination of the plane change requirement which saves approximately 1500 fps of delta V. An additional operational benefit of an equatorial launch site is the opening of the launch window to almost "at will" launch instead of the total of about 3 hours daily available at 28.5° KSC launch site. Future studies will investigate more thoroughly the technical and other trade-offs for various launch sites combined with low Earth staging orbits. Western U.S. launch sites are discussed in Section VI-B-6 of this report.

Transportation Fleet Description

Vehicle characteristics for the space transportation fleet were synthesized for input to the scenario computer program. In-house and contractor studies served as background and reference data for developing the detailed vehicle data. Projected ranges of technology (performance, weights, and costs) were used in sizing the minimum cost (MIN), nominal cost (NOM), and maximum cost (MAX) vehicle derivatives. Cost per flight estimations include production with learning, propellant, and operations/manpower costs.

Heavy Lift Launch Vehicle (HLLV) - The HLLV will be utilized for transport of all SPS hardware, OTV hardware and propellants, construction and support bases and consumables, and personnel consumables from Earth to LEO. Three candidate launch vehicles were identified in the FY 76 study and remain under consideration: complete winged entry/recovery, complete ballistic entry/recovery, winged entry/recovery with large external hydrogen tank expended. HLLV detail data may be found in Section VI-B of this report. The range of HLLV input data presented below represents a selection of characteristics judged to be typical of the final HLLV configuration design for a one million pound payload (gross) vehicle. The extremes of the HLLV cost per flight - $7 to $14M - reflect the range of uncertainty in defining the manpower and operations cost per flight.

	Min	Nom	Max
Payload/flt, tons (net)	445	424	382
Flt cost, \$M/flt	7	9	14
Flt turnaround, days	5	6	7
Mission life	400	300	200

Cargo Orbital Transfer Vehicle (COTV) - The COTV will be utilized for transport of all SPS hardware, GEO bases and consumables, and GEO personnel consumables from LEO to GEO. Several configurations have been identified in two basic categories of independent power (high thrust chemical) and dependent power (combined chemical/low thrust electrical propulsion).

For SPS geosynchronous construction, independent power is required of the COTV and based on studies to date, conventional LO_2/LH_2 high thrust propulsion is selected with a common stage option. "Min" and "Max" estimates were obtained by operating on the nominal values of payload. The range of $COTV_G$ (subscript "G" denoting SPS GEO construction) is described as follows:

	Min	Nom	Max
Payload, MT	300	250	200
Stages	2	2	2
Isp, sec	460	460	460
Total inert weight, MT	36	36	36
Prop weight, MT	574	574	574
Flt cost, \$M/flt	1.7	2.6	3.9
Flt turnaround, days	5	6	7
Mission life	100	50	25

For SPS LEO construction, a dependent power vehicle utilizing electrical propulsion for the transfer from LEO to GEO has been selected. Conventional O_2/H_2 chemical propulsion is required for attitude control during occultation periods. The SPS truss concept may be separated into 16 modules, each of which can provide electrical power to the electrical propulsion stages. Propulsion units are assumed to be mounted at each of four corners of each module. During the low thrust transfer to GEO, the SPS module makes several passes through the Van Allen Belt which causes degradation of

exposed solar array. Sizing of the $COTV_L$ accounts for the penalty of this satellite resizing as well as the electrical power distriubtion system (EPDS) added to the SPS array to provide power to the electric propulsion system. The $COTV_L$ mission life is limited to one mission; i.e., the system is expended or remains with the SPS module at GEO. The range of $COTV_L$ derived is described in Section VI-C-4 and is given as follows:

	Min	Nom	Max
Payload, MT	2926	5753	8828
Electric Propulsion			
Isp, sec	5000	5000	5000
η, %	70	65	55
Inert weight, MT	403	791	1269
Prop weight, MT	610	1291	2334
Chemical Propulsion			
Isp, sec	460	460	460
Inert weight, MT	19	38	144
Prop weight, MT	169	341	1059
Total Vehicle			
Inert weight, MT	422	829	1413
Prop weight, MT	779	1632	3393
Flt cost, $M/flt	41	88	146
Mission life	1	1	1

Personnel Orbital Transfer Vehicle (POTV) - The POTV will be utilized to transport all personnel from LEO to GEO and return. To minimize passenger exposure to the Van Allen belt radiation, a trip time of less than 1 day is required. Therefore, conventional high thrust LO_2/LH_2 cehmical propulsion is utilized. The common stage POTV is assumed utilized for both LEO and GEO assembly. The mission mode of the POTV takes advantage of the economies of the COTV by having its down propellant delivered to GEO by the COTV. Nominal vehicle chracteristics are unchanged from the FY 76 $POTV_L$ configuration. New cost data were derived with attendant flight and production unit buy numbers.

	Min	Nom	Max
Passengers	100	75	50
Isp, sec	462	462	462
Inert weight, MT	21	21	21
Prop up, MT	108	108	108
Prop down, MT	54	54	54
Flt cost $M/flt	2.4	3.0	3.8
Flt turnaround, days	5	6	7
Mission life	100	50	25

Personnel and Priority Cargo Launch Vehicle (PLV) - The PLV will be utilized for transport of all personnel from Earth to LEO and return. The PLV will be available for small loads of priority cargo, but this capability is not considered in this scenario exercise. Basically, the PLV is an upgraded Shuttle with the two baseline SRB's replaced by a "liquid replacement booster" (LRB) that operates in a series burn mode with the Orbiter/resized ET. The LRB is reusable following a ballistic entry and parachute/landing rockets water splashdown. The range of PLV characteristics is given as follows:

	Min	Nom	Max
Passengers/flt	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2
Flt turnaround, days	9	11	13
Mission life	150	100	50

Orbital Propellant Storage/Transfer Losses

For the SPS space transportation scenario, all OTV's are based at LEO for fueling, and flight vehicle turnaround activities. It was assumed that all OTV propellants are delivered to HLLV to a LEO depot "tank farm" or staging depot for propellant storage before OTV fueling. There will be propellant losses associated with this storage/transfer activity in terms of daily boiloff, transfer resideuals, and chilldown losses. Estimates for FY 76 have been refined and are presented in Section VI-C-1 per vehicle/mission type, i.e., $COTV_L$ POTV, or $COTV_G$. Due to the storage register limit with the HP-9810A scenario program,

$COTV_L$ and $POTV_L$ propellant mass loss percentage estimates of 7.0% and 5.4%, respectively, for LEO assembly have been combined by propellant mass usage ratioing into a single loss percentage of 6.9%. Similarly the $COTV_G$ and POTV propellant mass loss percentage of 6.1% and 5.4%, respectively, have been combined to obtain a single loss percentage of 6.1%. The special case of the POTV second stage return propellant was also treated and a propellant mass loss percentage of 10.8% and 19.0% determined for the GEO propellant handling mode for the $POTV_G$ and $POTV_L$, respectively. Thus, these data were input to the scenario program to account for the OTV preflight and flight ($COTV_L$ only) propellant losses and consequent additional launch costs.

SPS Construction/Personnel/Logistics Data Input

The range of satellite mass inputs were provided by Mr. Lou Livingston of the Spacecraft Design Division and were sized upward for the LEO assembly case to account for solar cell degradation during the low thrust LEO to GEO transfer. These data were 45,000; 78,000; and 113,000 metric tons for the range of GEO assembly satellite masses. Resulting data for LEO assembly with satellite resize penalty were 46,816; 92,048; and 141,248 metric tons, respectively. Construction and staging bases consumables were estimated at 1000 metric tons per year per SPS distributed between LEO and GEO. Personnel consumables were estimated at 200 kg per man-month (Boeing NAS 9-15196 estimate). Personnel count at LEO and GEO for both LEO and GEO assembly options is contained in the following table:

		Min	Nom	Max
GEO assembly:	GEO personnel	507	724	941
	LEO personnel	77	110	143
LEO assembly:	GEO personnel	235	335	436
	LEO personnel	508	726	944

Program Output Results

Annual and total 16 year (half program life) scenario runs have been completed for the two SPS assembly options for the two implementation schedules (Figure VI-F-1):

Concept 1: Truss SPS constructed at GEO

Concept 2: Truss SPS constructed at LEO

Man-trips, cargo mass, number of vehicle flights, fleet and replacement unit requirements are computed. Costs are computed for each vehicle as well as the specific costs expressed in \$/KWe buss and \$/kg SPS.

Table VI-F-1 presents the Scenario A' 16-year computer printouts for annual activity for construction plus repair. Nominal fleet size build up over the 16-year period is presented on Figure VI-F-2 (Concept 1) and Figure VI-F-3 (Concept 2).

Table VI-F-2 presents the Scenario C' 16 year computer printouts for annual activity for construction plus repair. Nominal fleet size build up over the 16-year period is presented on Figure VI-F-4 (Concept 1) and Figure VI-F-5 (Concept 2). The maximum fleet size (nominal) is compared in Table VI-F-3 for Scenarios A' and C'.

Tables VI-F-4 and -5 present the total 16 year computer printout for construction only, Scenarios A' and C', respectively. The runs sum all flight numbers and cost data for the entire period.

Tables VI-F-6 and -7 present the total 16 year computer printout for repair only, Scenarios A' and C', respectively. The runs sum all flight numbers and cost data for the entire period.

Tables VI-F-8 and -9 present the total 16 year computer printout for construction plus repair Scenarios A' and C', respectively. The runs sum all flight numbers and cost data for the entire period. Percentage costs expressed in $/KWe are shown for SPS mass and construction/repair logistics, OTV propellant launch costs, COTV flight costs, and manned support in Figures VI-F-6 and -7 for the nominal results of both GEO and LEO construction, Scenarios A' and C', respectively.

$COTV_L$ Performance Variance Sensitivity

The sensitivity to $COTV_L$ performance variance has been developed by running the scenario program over the nominal SPS mass, personnel, bases, and consumables, POTV, PLV, and HLLV values for Scenario C'. Table VI-F-10 presents the total 16 year computer printout for construction plus repair. This run sums all flight numbers and cost data for the entire period. Table VI-F-11 minimizes the $COTV_L$ spread and consequent $/kg SPS and $/KWe buss spread. The defined range of $COTV_L$ characteristics produced a range in $/KWe buss about the nominal value ($482) of -13% to +14% and a range in $/kg SPS about the nominal value ($52.35) of -1% to +7%.

HLLV Cost Per Flight Variance Sensitivity

The sensitivity to HLLV cost per flight variance has been developed by running the scenario program over the nominal SPS mass, personnel, bases, and consumables, POTV, PLV, COTV, and HLLV payload values for Scenario C'. Table VI-F-12 presents the total 16 year computer printout for construction plus repair for HLLV costs per flight

of ($M, 1977) 4, 6, 8, 10, 12, 14, 16, 18, and 20. The effect of varying this cost is seen on Figure VI-F-8 in a plot of $/KWe buss versus HLLV cost per flight. The GEO construction case is seen as twice as sensitive to HLLV cost per flight with a $\frac{\Delta \text{ \$/KWe buss}}{\Delta \text{ \$M cost/flt}}$ of 71 as compared to a $\frac{\Delta \text{ \$/KWe buss}}{\Delta \text{ \$M cost/flt}}$ of 35 for LEO construction. Figure VI-F-9 is a plot of $/kg SPS versus HLLV cost per flight. Again, the GEO construction case is seen as more sensitive to HLLV cost per flight. The FY 77 "Nominal" HLLV cost per flight estimate is $9M/flight for reference.

Transportation Cost Sensitivity for Nominal SPS

Inputs of nominal SPS mass, personnel, bases, and consumables were used over the range of inputs for the space transportation vehicles for the construction plus repair case (Scenario C'). Table VI-F-13 presents the computer printout for this case. Table VI-F-14 summarizes the results in terms of contributing component vehicle flight costs (HLLV, PLV, COTV, POTV) to the total specific transportation cost of $/kg SPS. Table VI-F-15 summarizes the results in terms of contributing component vehicle flight costs (HLLV, PLV, COTV, POTV) to the total specific transportation cost of $/KWe buss. The HLLV component vehicle flight cost is seen to comprise 83% and 62% of the total transportation cost in the nominal column for SPS GEO and LEO construction locations, respectively. The COTV component vehicle flight cost is seen to comprise 12% and 30% of the costs similarly. The manned support PLV and POTV combined component flight cost is 5% and 9% of the costs for GEO and LEO construction options, respectively.

Concluding Remarks

As in the FY 76 results, the HLLV dominates the SPS transportation cost and operations picture. The accuracy of the HLLV cost per flight estimation is critical; thus, the complexities of operating the large fleet of HLLV in multiple daily flights need thorough study to evolve more realistic operations/manpower cost estimates for each HLLV flight. This area is now estimated to comprise 1/3 to 1/2 of the cost per flight which represents approximately 35% and 26% of the total SPS transportation costs for GEO and LEO construction, respectively.

For the LEO construction case, the cost advantages of the $COTV_L$ with its lower propellant requirement are obvious in comparison to the conventional $COTV_G$. With consequent lower HLLV flights required, the option of self-powered transfer by $COTV_L$ is 1/3 less costly as the option of chemical propulsion high thrust transfer for SPS GEO construction. However, in terms of technical risk involved, the $COTV_G$ vehicle and operations are better understood than the $COTV_L$ at this time.

The area of OTV orbital propellant handling losses was reduced in impact on the total transportation cost from the FY 76 to the FY 77 studies. Mass loss percentages and consequent HLLV tanker launch costs dropped as a result of the funded study effort developing new data in this area. More accurate loss estimates and concepts of the LEO OTV staging operations are expected as results from the funded effort in early CY 1978.

Manned support cost percentages remain less than 10% of the total transportation costs. Doubling the manpower or reducing the crew rotation period of 180 days to 90 days, for instance, would not greatly effect the total transportation costs.

SCENARIO A':

CY	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	10
New SPS On-Line	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	1	1	1	$1\frac{1}{2}$	2	2	2	2	2	2	2	2
Total SPS On-Line	$\frac{1}{4}$	$\frac{1}{2}$	1	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	6	8	10	12	14	16	18	20	22
SPS Repair/ Maint.	0	$\frac{1}{4}$	$\frac{1}{2}$	1	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	6	8	10	12	14	16	18	20

SCENARIO C':

CY	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	10
New SPS On-Line	1	1	1	1	2	2	2	2	3	3	4	4	5	5	5	5
Total SPS On-Line	1	2	3	4	6	8	10	12	15	18	22	26	31	36	41	46
SPS Repair/ Maint.	0	1	2	3	4	6	8	10	12	15	18	22	26	31	36	41

Figure VI-F-1. SPS Placement and Repair Schedules

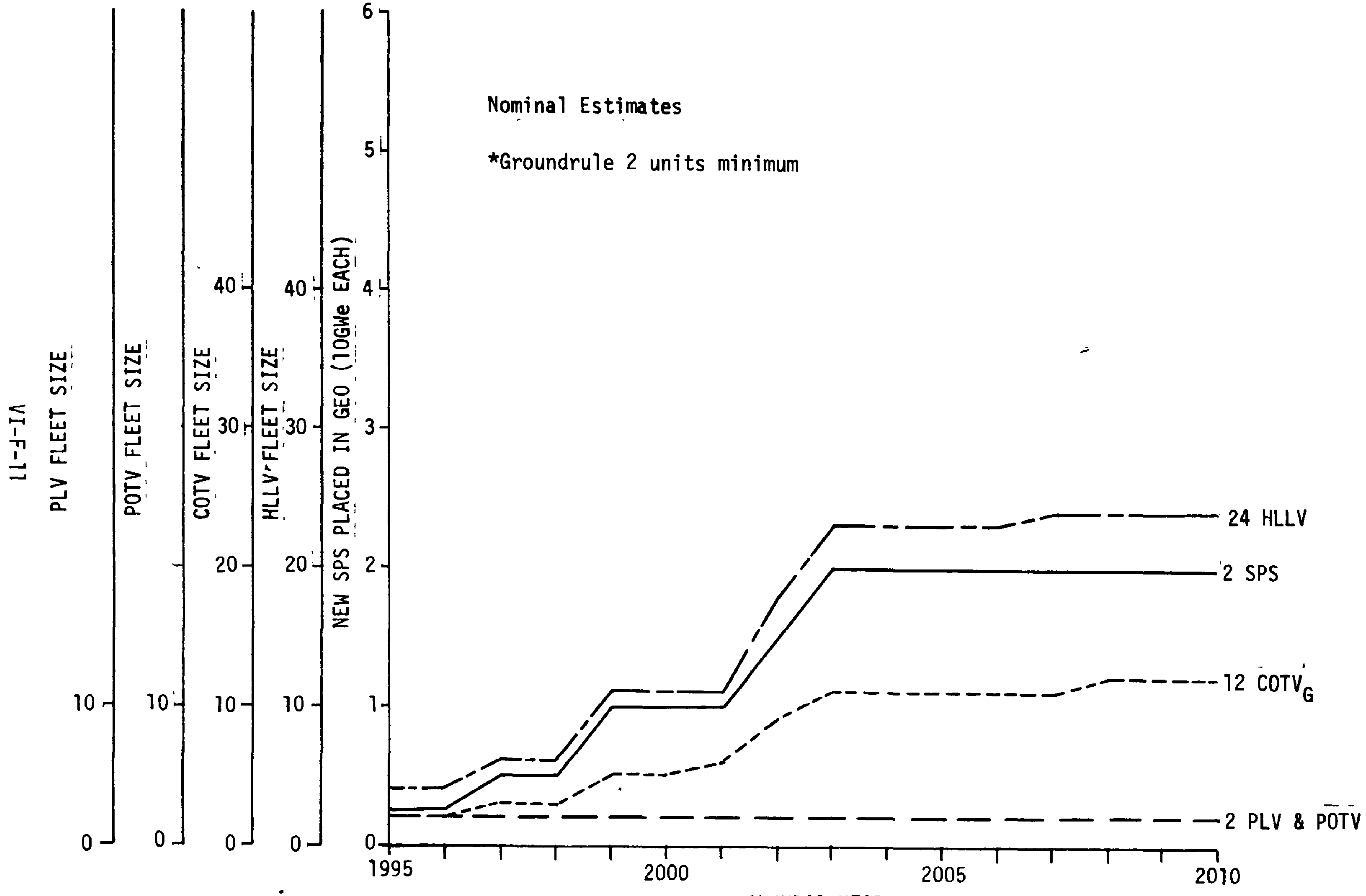

Figure VI-F-2. SPS Transportation Fleet Size Buildup GEO Construction - Scenario A'

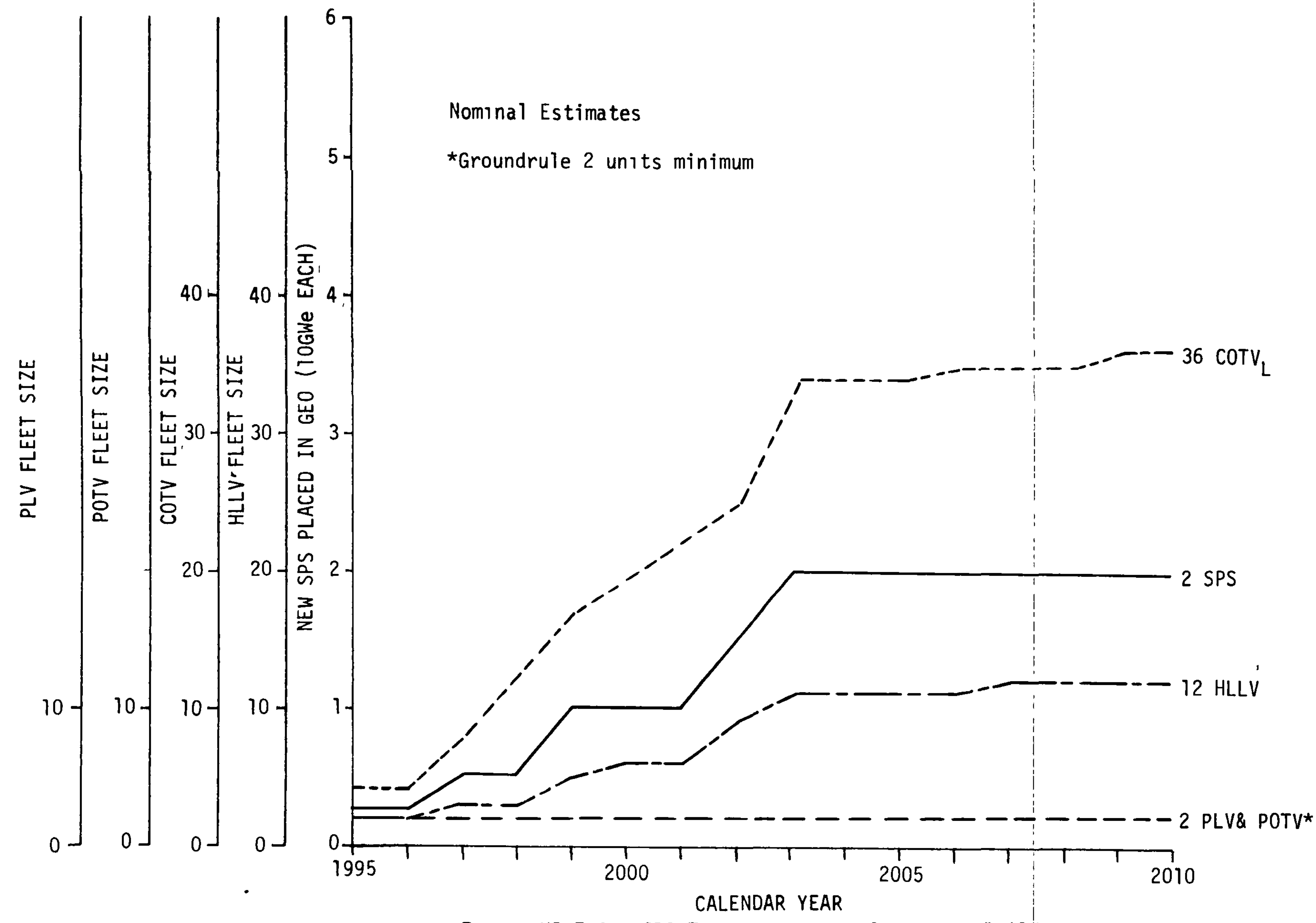

Figure VI-F-3. SPS Transportation Fleet Size Buildup LEO Construction - Scenario A'

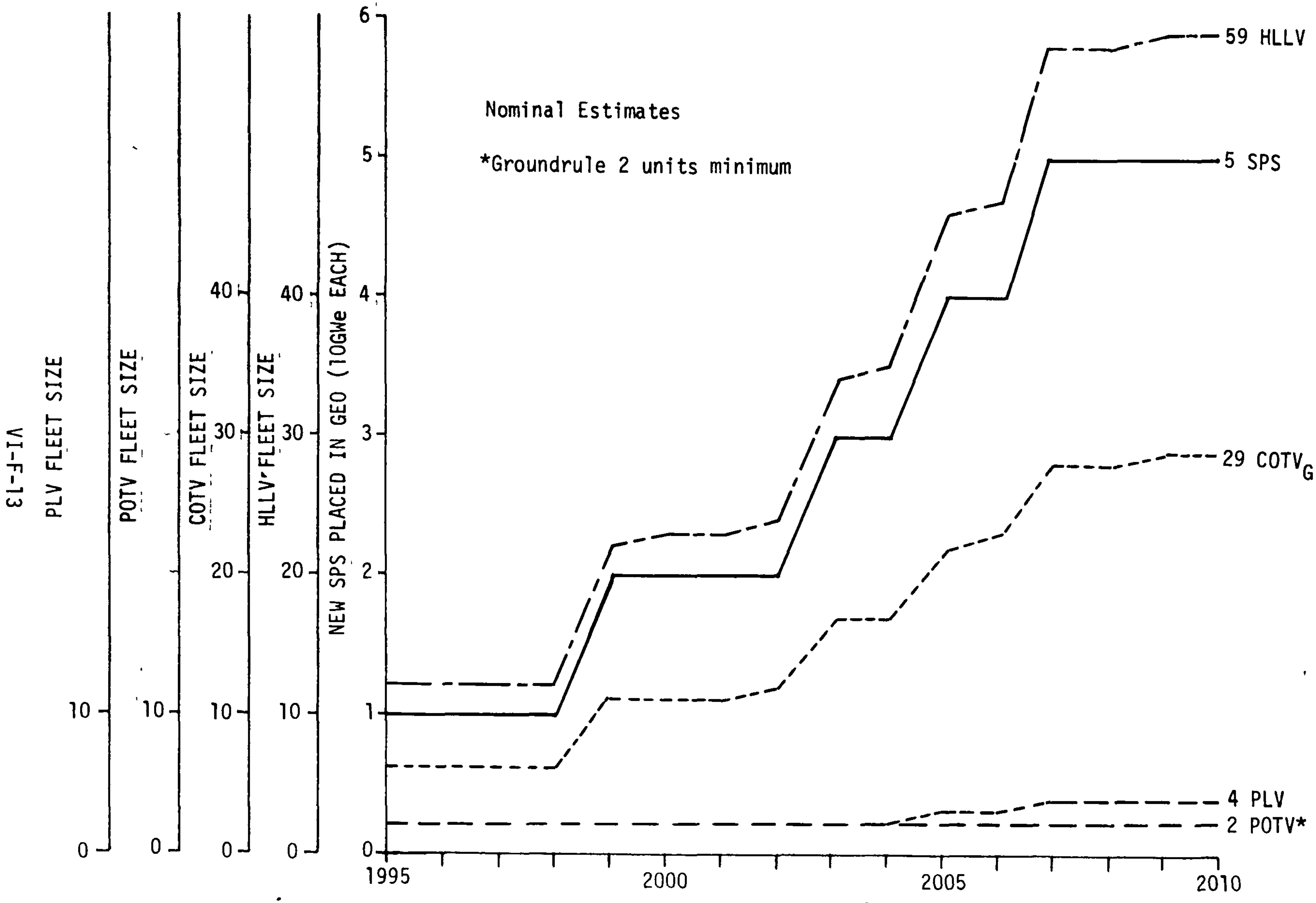

Figure VI-F-4. SPS Transportation Fleet Size Buildup
GEO Construction - Scenario C'

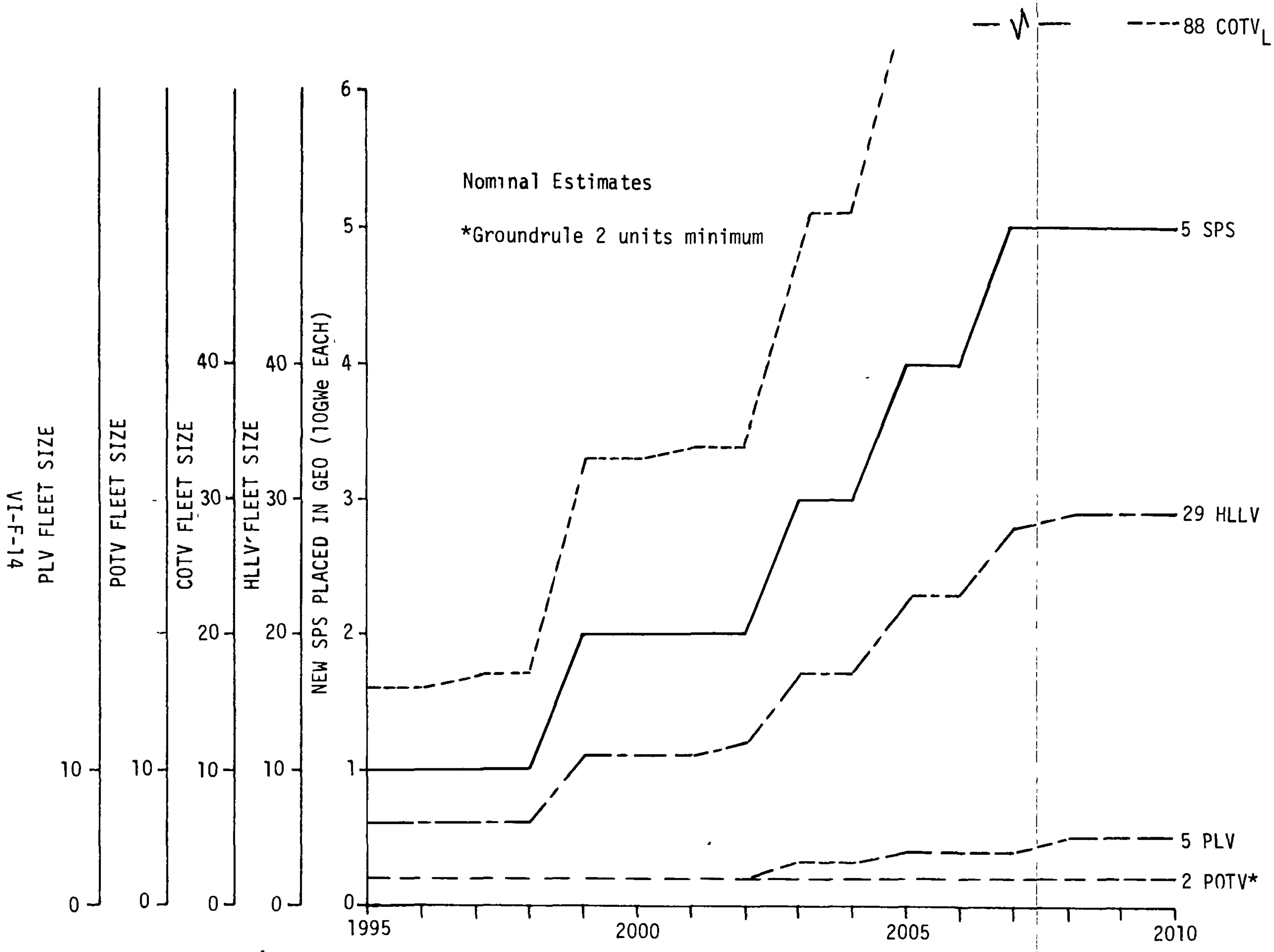

Figure VI-F-5. SPS Transportation Fleet Size Buildup
LEO Construction - Scenario C'

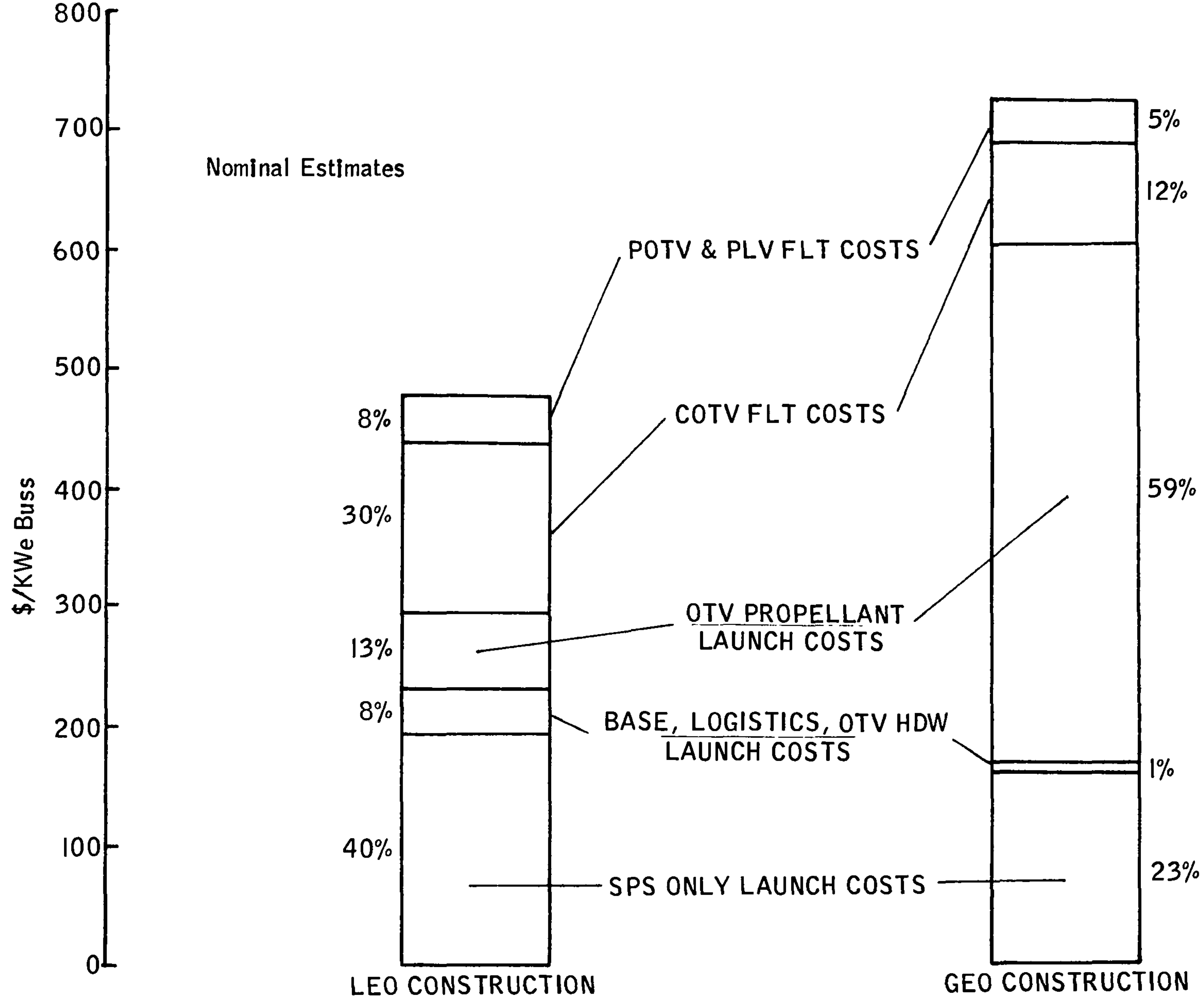

Figure VI-F-6. SPS Transportation Cost Summary
Construction Only - Scenario A'

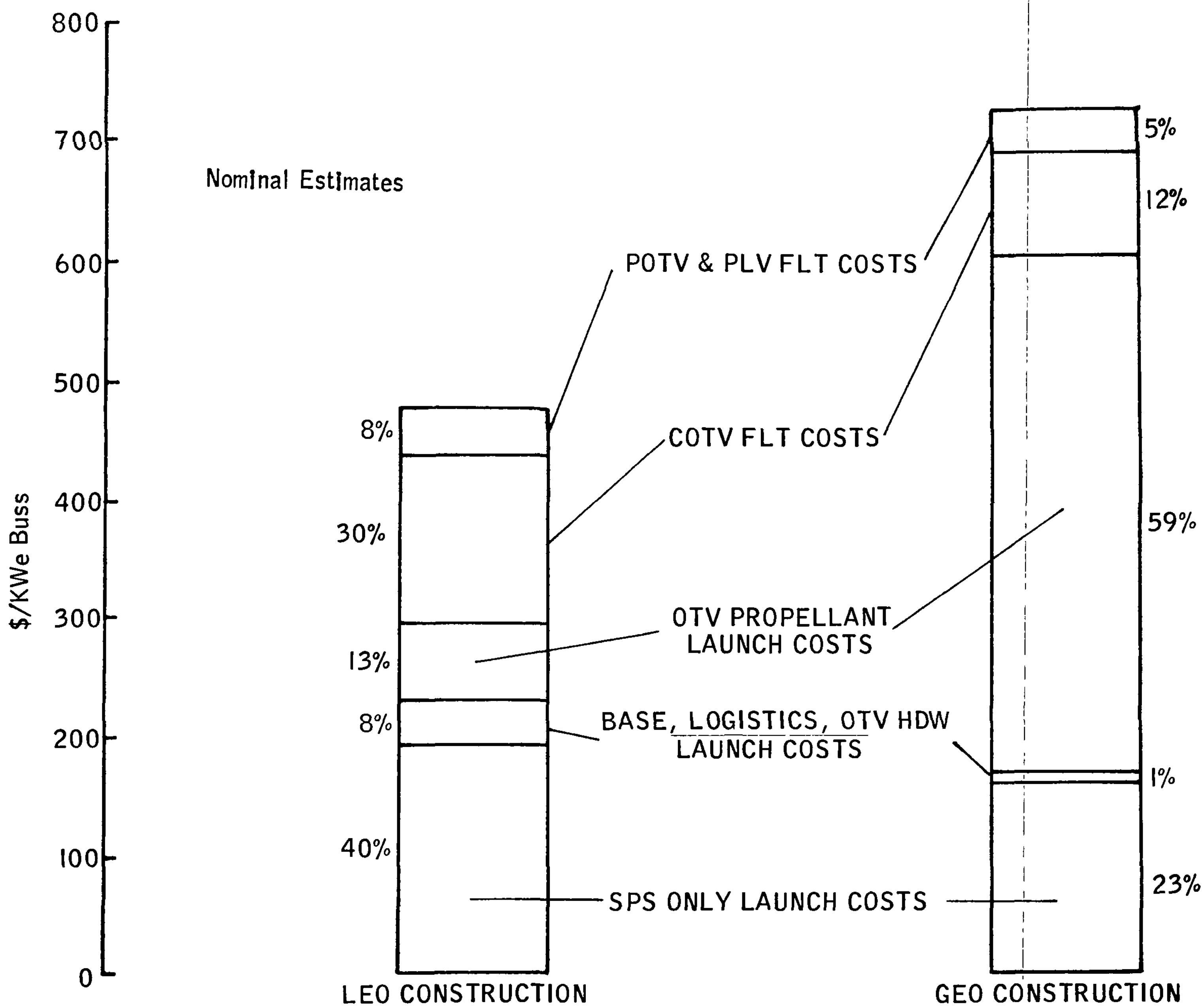

Figure VI-F-7. SPS Transportation Cost Summary Construction Only - Scenario C'

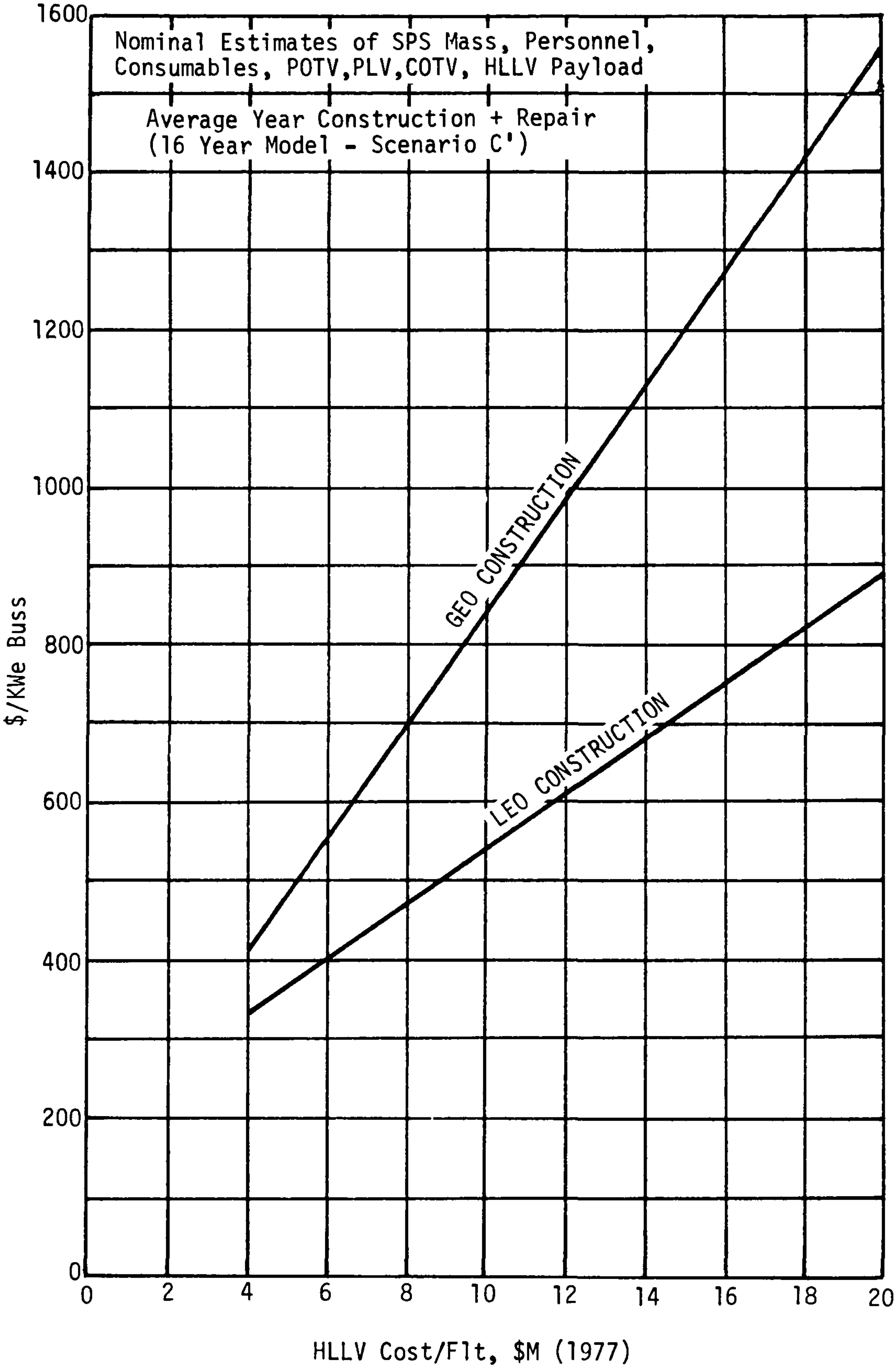

Figure VI-F-8. $/KWe Buss versus HLLV Cost/Flt

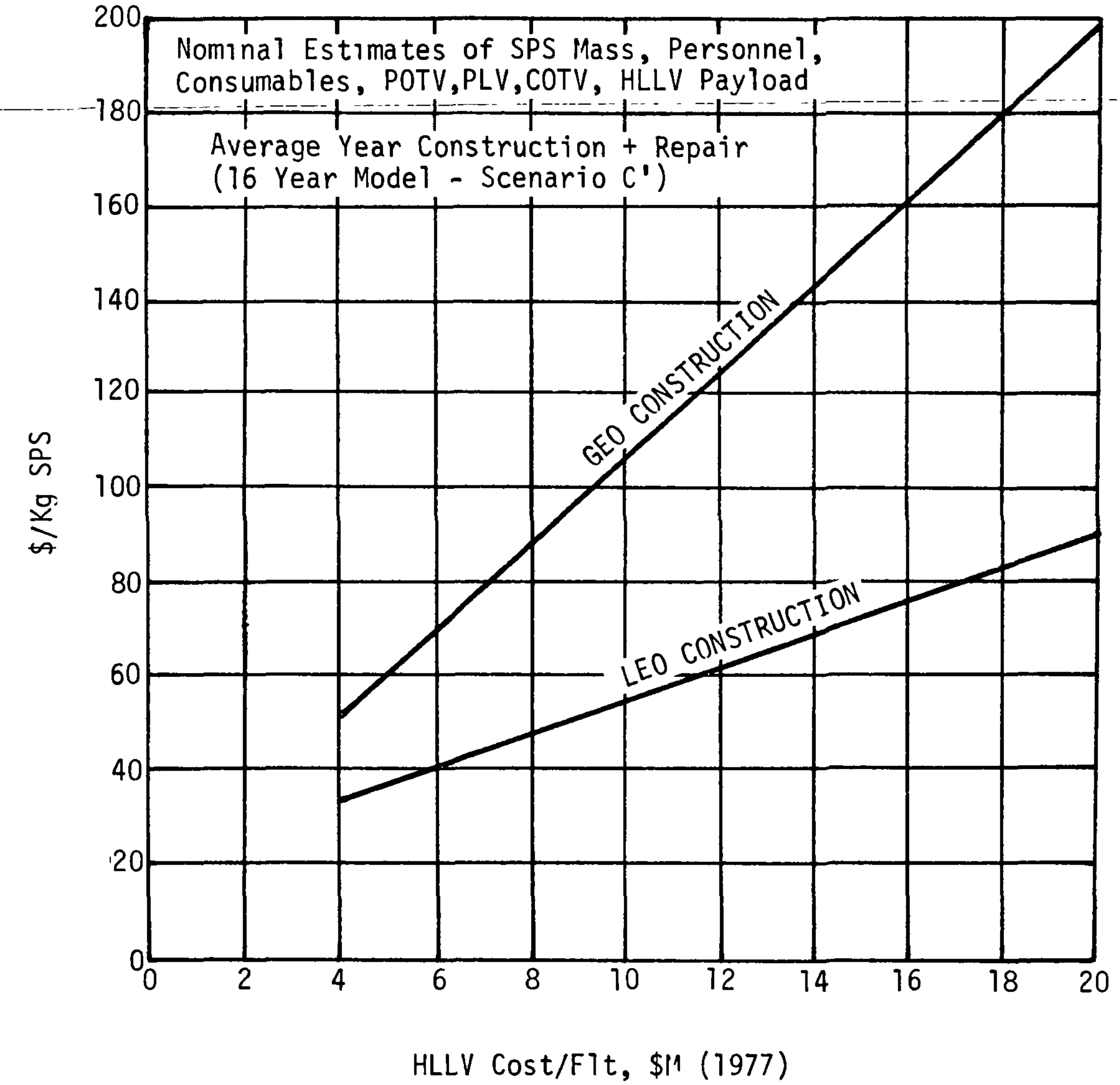

Figure VI-F-9. $/Kg SPS versus HLLV Cost/Flt

Construction + Repair
Scenario A'

TABLE VI-F-1
YEAR 1995 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates) (Typical of Base Instll. yrs.)

6/20/77

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	0.3	0.3	0.3	0.3	0.3	0.3
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
GEO persnl/SPS	507	724	941	235	335	436
GEO persnl consum/SPS, 10^3T	0.852	1.738	2.936	0.395	0.804	1.360
GEO Base, 10^3T	3.000	6.000	9.000	0.750	1.000	1.250
GEO Base equip&consum/SPS, 10^3T	0.668	0.868	1.129	0.221	0.316	0.411
LEO persnl/SPS	77	110	143	508	726	944
LEO persnl consum/SPS, 10^3T	0.129	0.264	0.446	0.853	1.742	2.945
LEO Base, 10^3T	0.750	1.000	1.250	3.000	6.000	9.000
LEO Base equip&consum/SPS, 10^3T	0.092	0.132	0.171	0.479	0.684	0.889
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	2.926	5.753	8.828
Total inert wt, 10^3T	0.036	0.036	0.036	0.422	0.829	1.413
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	0.779	1.632	3.393
Flt cost, $M/flt	1.7	2.6	3.9	41.0	88.0	146.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, $M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1995 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	0.250	0.250	0.250	0.250	0.250	0.250
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	11.250	19.500	28.250	11.704	23.012	35.312
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	254	362	471	118	168	218
POTV flts/yr	3	5	9	1	2	4
POTV prop wt, 10^3T/yr	0.41	0.78	1.52	0.19	0.36	0.71
POTV flt cost, $M/yr	6	14	36	3	7	17
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	1	2	4	0	1	2
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	292	417	542	372	531	690
PLV flts/yr	3	6	11	4	7	14
PLV flt cost, $M/yr	30	75	176	38	95	224
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	0.17	0.22	0.28	0.06	0.08	0.10
Persnl consum, 10^3T/yr	0.21	0.43	0.73	0.10	0.20	0.34
COTV flts/yr	11	27	50	0	0	0
HLLV flts/yr	8	16	26	2	3	4
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.02	0.03	0.04	0.12	0.17	0.22
Persnl consum, 10^3T/yr	0.03	0.07	0.11	0.21	0.44	0.74
HLLV flts/yr	2	3	4	7	16	26

TABLE VI-F-1 (CONT'D)

YEAR 1995 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	11.250	19.500	28.250	11.704	23.012	35.312
COTV flts/yr	38	78	141	4	4	4
HLLV flts/yr	25	46	74	26	54	92
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	14.773	26.424	38.798	12.679	24.427	37.269
Total COTV flts/yr	49	106	194	4	4	4
COTV prop wt, 10^3T/yr	28.27	60.67	111.35	3.38	6.93	14.32
COTV flt cost, $M/yr	84	275	757	178	374	616
COTV fleet size, units	2	2	4	4	4	4
COTV replacement, units	0	0	4	0	0	0
HLLV flts/yr	67	152	310	12	26	56
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	45.89	92.54	159.74	21.59	42.23	69.03
Total HLLV flts/yr	103	218	418	49	100	181
HLLV flt cost, $M/yr	722	1964	5854	340	896	2530
HLLV fleet size, units	2	4	8	2	2	3
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	6	14	36	3	7	17
PLV flt cost, $M/yr	30	75	176	38	95	224
COTV flt cost, $M/yr	84	275	757	178	374	616
Subtotal	120	364	968	218	476	856
HLLV flt cost, $M/yr	722	1964	5854	340	896	2530
TOTAL TRANSPORTATION COST $M	841	2329	6822	558	1372	3386
Specific cost, $/Kg SPS	74.79	119.42	241.50	47.67	59.63	95.90

TABLE VI-F-1 (CONT'D)
YEAR 1996 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates) (Typical of non-Base Instll. yrs.)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	0.3	0.3	0.3	0.3	0.3	0.3
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
GEO persnl/SPS	507	724	941	235	335	436
GEO persnl consum/SPS, 10^3T	0.852	1.738	2.936	0.395	0.804	1.360
GEO Base, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
GEO Base equip&consum/SPS, 10^3T	0.668	0.868	1.129	0.221	0.316	0.411
LEO persnl/SPS	77	110	143	508	726	944
LEO persnl consum/SPS, 10^3T	0.129	0.264	0.446	0.853	1.742	2.945
LEO Base, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
LEO Base equip&consum/SPS, 10^3T	0.092	0.132	0.171	0.479	0.684	0.889
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, \$M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, \$M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	2.926	5.753	8.828
Total inert wt, 10^3T	0.036	0.036	0.036	0.422	0.829	1.413
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	0.779	1.632	3.393
Flt cost, \$M/flt	1.7	2.6	3.9	41.0	88.0	146.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, \$M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1996 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	0.253	0.253	0.253	0.253	0.253	0.253
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	11.363	19.695	28.533	11.821	23.242	35.665
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	256	366	475	119	169	220
POTV flts/yr	3	5	10	1	2	4
POTV prop wt, 10^3T/yr	0.41	0.79	1.54	0.19	0.37	0.71
POTV flt cost, $M/yr	6	15	36	3	7	17
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	1	2	4	0	1	2
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	295	421	547	375	536	697
PLV flts/yr	3	6	11	4	7	14
PLV flt cost, $M/yr	30	76	177	38	96	226
PLV fleet size, units	?	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.17	0.22	0.29	0.06	0.08	0.10
Persnl consum, 10^3T/yr	0.22	0.44	0.74	0.10	0.20	0.34
COTV flts/yr	1	3	5	0	0	0
HLLV flts/yr	1	2	3	0	1	1
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.02	0.03	0.04	0.12	0.17	0.22
Persnl consum, 10^3T/yr	0.03	0.07	0.11	0.22	0.44	0.74
HLLV flts/yr	0	0	0	1	1	3

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1996 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	11.363	19.695	28.533	11.821	23.242	35.665
COTV flts/yr	38	79	143	4	4	4
HLLV flts/yr	26	46	75	27	55	93
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	11.891	20.629	30.096	12.048	23.661	36.379
Total COTV flts/yr	40	83	150	4	4	4
COTV prop wt, 10^3T/yr	22.75	47.36	86.38	3.21	6.71	13.98
COTV flt cost, $M/yr	67	215	587	169	362	602
COTV fleet size, units	2	2	3	4	4	4
COTV replacement, units	0	0	3	0	0	0
HLLV flts/yr	54	119	240	12	25	54
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	36.40	71.62	123.24	17.69	35.13	58.65
Total HLLV flts/yr	82	169	323	40	83	154
HLLV flt cost, $M/yr	573	1520	4517	278	746	2149
HLLV fleet size, units	2	3	6	2	2	3
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	6	15	36	3	7	17
PLV flt cost, $M/yr	30	76	177	38	96	226
COTV flt cost, $M/yr	67	215	587	169	362	602
Subtotal	104	305	800	210	465	844
HLLV flt cost, $M/yr	573	1520	4517	278	746	2149
TOTAL TRANSPORTATION COST $M	676	1825	5317	488	1211	2993
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1997 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	0.505	0.505	0.505	0.505	0.505	0.505
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	22.725	39.390	57.065	23.642	46.484	71.330
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	512	731	950	237	338	440
POTV flts/yr	5	10	19	2	5	9
POTV prop wt, 10^3T/yr	0.83	1.58	3.08	0.38	0.73	1.43
POTV flt cost, $M/yr	12	29	72	6	14	33
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	2	4	9	1	2	4
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	590	842	1095	750	1072	1394
PLV flts/yr	6	11	22	8	14	28
PLV flt cost, $M/yr	60	152	355	77	193	452
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.34	0.44	0.57	0.11	0.16	0.21
Persnl consum, 10^3T/yr	0.43	0.88	1.48	0.20	0.41	0.69
COTV flts/yr	3	5	10	0	0	0
HLLV flts/yr	2	3	5	1	1	2
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.05	0.07	0.09	0.24	0.35	0.45
Persnl consum, 10^3T/yr	0.07	0.13	0.23	0.43	0.88	1.49
HLLV flts/yr	0	0	1	2	3	5

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1997 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	22.725	39.390	57.065	23.642	46.484	71.330
COTV flts/yr	76	158	285	8	8	8
HLLV flts/yr	51	93	149	53	110	187
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	23.782	41.257	60.193	24.097	47.323	72.758
Total COTV flts/yr	79	165	301	8	8	8
COTV prop wt, 10^3T/yr	45.50	94.73	172.75	6.42	13.42	27.96
COTV flt cost, $M/yr	135	429	1174	338	724	1203
COTV fleet size, units	2	3	6	8	8	8
COTV replacement, units	0	1	6	0	0	0
HLLV flts/yr	109	237	481	23	50	109
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	72.81	143.23	246.48	35.39	70.26	117.29
Total HLLV flts/yr	164	338	645	80	166	307
HLLV flt cost, $M/yr	1145	3040	9033	557	1491	4299
HLLV fleet size, units	2	6	12	2	3	6
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	12	29	72	6	14	33
PLV flt cost, $M/yr	60	152	355	77	193	452
COTV flt cost, $M/yr	135	429	1174	338	724	1203
Subtotal	207	610	1601	420	930	1688
HLLV flt cost, $M/yr	1145	3040	9033	557	1491	4299
TOTAL TRANSPORTATION COST $M	1352	3650	10634	977	2422	5987
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1998 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	0.510	0.510	0.510	0.510	0.510	0.510
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	22.950	39.780	57.630	23.876	46.944	72.036
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	517	738	960	240	342	445
POTV flts/yr	5	10	19	2	5	9
POTV prop wt, 10^3T/yr	0.84	1.60	3.11	0.39	0.74	1.44
POTV flt cost, $M/yr	12	30	73	6	14	34
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	2	4	9	1	2	4
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	596	851	1106	758	1082	1408
PLV flts/yr	6	11	22	8	14	28
PLV flt cost, $M/yr	61	153	358	77	195	456
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.34	0.44	0.58	0.11	0.16	0.21
Persnl consum, 10^3T/yr	0.43	0.89	1.50	0.20	0.41	0.69
COTV flts/yr	3	5	10	0	0	0
HLLV flts/yr	2	3	5	1	1	2
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.05	0.07	0.09	0.24	0.35	0.45
Persnl consum, 10^3T/yr	0.07	0.13	0.23	0.44	0.89	1.50
HLLV flts/yr	0	0	1	2	3	5

TABLE VI-F-1 (CONT'D)

YEAR 1998 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	22.950	39.780	57.630	23.876	46.944	72.036
COTV flts/yr	77	159	288	8	8	8
HLLV flts/yr	52	94	151	54	111	189
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	24.018	41.666	60.788	24.326	47.773	73.443
Total COTV flts/yr	80	167	304	8	8	8
COTV prop wt, 10^3T/yr	45.95	95.66	174.46	6.48	13.55	28.23
COTV flt cost, $M/yr	136	433	1185	341	731	1215
COTV fleet size, units	2	3	6	8	8	8
COTV replacement, units	0	1	6	0	0	0
HLLV flts/yr	110	240	486	23	50	109
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	73.53	144.65	248.93	35.67	70.81	118.16
Total HLLV flts/yr	165	341	652	80	167	309
HLLV flt cost, $M/yr	1157	3070	9123	561	1503	4330
HLLV fleet size, units	2	6	12	2	3	6
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	12	30	73	6	14	34
PLV flt cost, $M/yr	61	153	358	77	195	456
COTV flt cost, $M/yr	136	433	1185	341	731	1215
Subtotal	209	616	1617	424	939	1704
HLLV flt cost, $M/yr	1157	3070	9123	561	1503	4330
TOTAL TRANSPORTATION COST $M	1366	3686	10739	985	2442	6035
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.25	52.03	83.78

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1999 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	1.015	1.015	1.015	1.015	1.015	1.015
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	45.675	79.170	114.695	47.518	93.429	143.367
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1029	1470	1910	477	680	885
POTV flts/yr	10	20	38	5	9	18
POTV prop wt, 10^3T/yr	1.67	3.17	6.19	0.77	1.47	2.87
POTV flt cost, \$M/yr	25	59	145	11	27	67
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	18	2	4	8
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1186	1693	2201	1508	2154	2801
PLV flts/yr	12	23	44	15	29	56
PLV flt cost, \$M/yr	121	305	713	154	388	908
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.68	0.88	1.15	0.22	0.32	0.42
Persnl consum, 10^3T/yr	0.86	1.76	2.98	0.40	0.82	1.38
COTV flts/yr	5	11	21	0	0	0
HLLV flts/yr	3	6	11	1	3	5
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.09	0.13	0.17	0.49	0.69	0.90
Persnl consum, 10^3T/yr	0.13	0.27	0.45	0.87	1.77	2.99
HLLV flts/yr	1	1	2	3	6	10

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 1999 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3 T/yr	45.675	79.170	114.695	47.518	93.429	143.367
COTV flts/yr	152	317	573	16	16	16
HLLV flts/yr	103	187	300	107	220	375
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	47.800	82.923	120.981	48.432	95.114	146.236
Total COTV flts/yr	159	332	605	17	17	17
COTV prop wt, 10^3 T/yr	91.46	190.39	347.22	12.89	26.98	56.21
COTV flt cost, $M/yr	271	862	2359	679	1455	2418
COTV fleet size, units	2	5	12	17	17	17
COTV replacement, units	0	1	13	0	0	0
HLLV flts/yr	218	477	967	47	100	219
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	146.33	287.89	495.41	71.12	141.21	235.74
Total HLLV flts/yr	329	679	1297	160	333	617
HLLV flt cost, $M/yr	2302	6111	18156	1119	2997	8640
HLLV fleet size, units	5	11	25	2	5	12
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	25	59	145	11	27	67
PLV flt cost, $M/yr	121	305	713	154	388	908
COTV flt cost, $M/yr	271	862	2359	679	1455	2418
Subtotal	416	1226	3217	844	1870	3393
HLLV flt cost, $M/yr	2302	6111	18156	1119	2997	8640
TOTAL TRANSPORTATION COST $M	2718	7337	21374	1963	4867	12033
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2000 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	1.025	1.025	1.025	1.025	1.025	1.025
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	46.125	79.950	115.825	47.986	94.349	144.779
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1039	1484	1929	482	687	894
POTV flts/yr	10	20	39	5	9	18
POTV prop wt, 10^3T/yr	1.68	3.21	6.25	0.78	1.48	2.90
POTV flt cost, $M/yr	25	59	147	12	27	68
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	18	2	4	8
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1197	1710	2222	1523	2175	2829
PLV flts/yr	12	23	44	15	29	57
PLV flt cost, $M/yr	122	308	720	155	392	917
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.68	0.89	1.16	0.23	0.32	0.42
Persnl consum, 10^3T/yr	0.87	1.78	3.01	0.40	0.82	1.39
COTV flts/yr	5	11	21	0	0	0
HLLV flts/yr	4	6	11	1	3	5
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.09	0.14	0.18	0.49	0.70	0.91
Persnl consum, 10^3T/yr	0.13	0.27	0.46	0.87	1.79	3.02
HLLV flts/yr	1	1	2	3	6	10

TABLE VI-F-1 (CONT'D)

YEAR 2000 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	46.125	79.950	115.825	47.986	94.349	144.779
COTV flts/yr	154	320	579	16	16	16
HLLV flts/yr	104	189	303	108	223	379
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	48.271	83.740	122.173	48.909	96.051	147.677
Total COTV flts/yr	161	335	611	17	17	17
COTV prop wt, 10^3T/yr	92.36	192.27	350.64	13.02	27.25	56.76
COTV flt cost, $M/yr	274	871	2382	685	1469	2442
COTV fleet size, units	2	5	12	17	17	17
COTV replacement, units	0	1	13	0	0	0
HLLV flts/yr	220	482	976	47	101	221
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	147.77	290.72	500.29	71.82	142.60	238.06
Total HLLV flts/yr	332	686	1310	161	336	623
HLLV flt cost, $M/yr	2325	6171	18335	1130	3027	8725
HLLV fleet size, units	5	11	25	2	6	12
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	25	59	147	12	27	68
PLV flt cost, $M/yr	122	308	720	155	392	917
COTV flt cost, $M/yr	274	871	2382	685	1469	2442
Subtotal	421	1238	3249	852	1888	3427
HLLV flt cost, $M/yr	2325	6171	18335	1130	3027	8725
TOTAL TRANSPORTATION COST $M	2745	7409	21584	1982	4915	12152
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2001 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.035	1.035	1.035	1.035	1.035	1.035
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	46.575	80.730	116.955	48.455	95.270	146.192
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1049	1499	1948	486	693	903
POTV flts/yr	10	20	39	5	9	18
POTV prop wt, 10^3T/yr	1.70	3.24	6.31	0.79	1.50	2.92
POTV flt cost, $M/yr	25	60	148	12	28	69
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	18	2	4	9
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1209	1726	2244	1538	2196	2857
PLV flts/yr	12	23	45	15	29	57
PLV flt cost, $M/yr	123	311	727	157	395	926
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.69	0.90	1.17	0.23	0.33	0.43
Persnl consum, 10^3T/yr	0.88	1.80	3.04	0.41	0.83	1.41
COTV flts/yr	5	11	21	0	0	0
HLLV flts/yr	4	6	11	1	3	5
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.10	0.14	0.18	0.50	0.71	0.92
Persnl consum, 10^3T/yr	0.13	0.27	0.46	0.88	1.80	3.05
HLLV flts/yr	1	1	2	3	6	10

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2001 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	46.575	80.730	116.955	48.455	95.270	146.192
COTV flts/yr	155	323	585	17	17	17
HLLV flts/yr	105	190	306	109	225	383
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	48.742	84.557	123.365	49.387	96.989	149.117
Total COTV flts/yr	162	338	617	17	17	17
COTV prop wt, 10^3T/yr	93.26	194.14	354.06	13.15	27.51	57.31
COTV flt cost, $M/yr	276	879	2406	692	1484	2466
COTV fleet size, units	2	6	12	17	17	17
COTV replacement, units	0	1	13	0	0	0
HLLV flts/yr	222	486	986	48	102	223
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	149.22	293.56	505.17	72.52	143.99	240.39
Total HLLV flts/yr	335	692	1322	163	340	629
HLLV flt cost, $M/yr	2347	6231	18514	1141	3056	8810
HLLV fleet size, units	5	11	25	2	6	12
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	25	60	148	12	28	69
PLV flt cost, $M/yr	123	311	727	157	395	926
COTV flt cost, $M/yr	276	879	2406	692	1484	2466
Subtotal	425	1250	3281	861	1907	3460
HLLV flt cost, $M/yr	2347	6231	18514	1141	3056	8810
TOTAL TRANSPORTATION COST $M	2772	7481	21795	2001	4963	12270
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2002 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.545	1.545	1.545	1.545	1.545	1.545
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	69.525	120.510	174.585	72.331	142.214	218.228
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1567	2237	2908	726	1035	1347
POTV flts/yr	16	30	58	7	14	27
POTV prop wt, 10^3T/yr	2.54	4.83	9.42	1.18	2.24	4.37
POTV flt cost, $M/yr	38	89	221	17	41	102
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	6	12	27	3	6	13
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1805	2577	3350	2296	3278	4264
PLV flts/yr	18	34	67	23	44	85
PLV flt cost, $M/yr	184	464	1085	234	590	1382
PLV fleet size, units	2	2	2	2	2	3
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	1.03	1.34	1.74	0.34	0.49	0.63
Persnl consum, 10^3T/yr	1.32	2.69	4.54	0.61	1.24	2.10
COTV flts/yr	18	40	76	1	0	0
HLLV flts/yr	12	24	40	4	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.14	0.20	0.26	0.74	1.06	1.37
Persnl consum, 10^3T/yr	0.20	0.41	0.69	1.32	2.69	4.55
HLLV flts/yr	2	4	6	11	23	39

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2002 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	69.525	120.510	174.585	72.331	142.214	218.228
COTV flts/yr	232	482	873	25	25	25
HLLV flts/yr	156	284	457	163	335	571
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	75.759	132.223	193.153	74.472	145.780	223.845
Total COTV flts/yr	253	529	966	25	25	25
COTV prop wt, 10^3T/yr	144.95	303.58	554.35	19.83	41.35	86.03
COTV flt cost, $M/yr	429	1375	3766	1044	2230	3702
COTV fleet size, units	3	9	19	25	25	25
COTV replacement, units	0	2	20	0	0	0
HLLV flts/yr	346	761	1543	72	154	335
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	232.59	459.85	791.82	112.33	222.39	369.80
Total HLLV flts/yr	523	1085	2073	252	525	968
HLLV flt cost, $M/yr	3659	9761	29019	1767	4721	13553
HLLV fleet size, units	7	18	40	3	9	19
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	38	89	221	17	41	102
PLV flt cost, $M/yr	184	464	1085	234	590	1382
COTV flt cost, $M/yr	429	1375	3766	1044	2230	3702
Subtotal	651	1928	5073	1295	2861	5186
HLLV flt cost, $M/yr	3659	9761	29019	1767	4721	13553
TOTAL TRANSPORTATION COST $M	4310	11689	34092	3062	7582	18739
Specific cost, $/Kg SPS	61.99	97.00	195.28	42.34	53.31	85.87

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2003 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.060	2.060	2.060	2.060	2.060	2.060
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	92.700	160.680	232.780	96.441	189.619	290.971
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2089	2983	3877	968	1380	1796
POTV flts/yr	21	40	78	10	18	36
POTV prop wt, 10^3T/yr	3.38	6.44	12.56	1.57	2.98	5.82
POTV flt cost, $M/yr	50	119	295	23	55	137
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	16	36	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2406	3436	4466	3061	4371	5686
PLV flts/yr	24	46	89	31	58	114
PLV flt cost, $M/yr	245	618	1447	312	787	1842
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.38	1.79	2.33	0.46	0.65	0.85
Persnl consum, 10^3T/yr	1.76	3.58	6.05	0.81	1.66	2.80
COTV flts/yr	10	21	42	0	0	0
HLLV flts/yr	7	13	22	3	5	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.19	0.27	0.35	0.99	1.41	1.83
Persnl consum, 10^3T/yr	0.27	0.54	0.92	1.76	3.59	6.07
HLLV flts/yr	1	2	3	6	12	21

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2003 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	92.700	160.680	232.780	96.441	189.619	290.971
COTV flts/yr	309	643	1164	33	33	33
HLLV flts/yr	208	379	609	217	447	762
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	97.012	168.297	245.538	98.296	193.040	296.794
Total COTV flts/yr	323	673	1228	34	34	34
COTV prop wt, 10^3T/yr	185.62	386.41	704.69	26.17	54.76	114.07
COTV flt cost, $M/yr	550	1750	4788	1377	2953	4908
COTV fleet size, units	4	11	24	34	34	34
COTV replacement, units	0	2	26	0	0	0
HLLV flts/yr	443	968	1962	95	204	444
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	296.99	584.28	1005.46	144.35	286.60	478.45
Total HLLV flts/yr	667	1378	2632	324	676	1252
HLLV flt cost, $M/yr	4672	12402	36849	2271	6083	17535
HLLV fleet size, units	9	23	50	4	11	24
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	50	119	295	23	55	137
PLV flt cost, $M/yr	245	618	1447	312	787	1842
COTV flt cost, $M/yr	550	1750	4788	1377	2953	4908
Subtotal	845	2488	6530	1713	3795	6887
HLLV flt cost, $M/yr	4672	12402	36849	2271	6083	17535
TOTAL TRANSPORTATION COST $M	5517	14890	43379	3983	9878	24422
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

TABLE VI-F-1 (CONT'D)

YEAR 2004 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.080	2.080	2.080	2.080	2.080	2.080
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	93.600	162.240	235.040	97.377	191.460	293.796
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2109	3012	3915	978	1394	1814
POTV flts/yr	21	40	78	10	19	36
POTV prop wt, 10^3T/yr	3.42	6.51	12.68	1.58	3.01	5.88
POTV flt cost, $M/yr	51	120	298	23	56	138
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	17	36	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2429	3469	4509	3091	4414	5741
PLV flts/yr	24	46	90	31	59	115
PLV flt cost, $M/yr	248	624	1461	315	794	1860
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.39	1.81	2.35	0.46	0.66	0.85
Persnl consum, 10^3T/yr	1.77	3.62	6.11	0.82	1.67	2.83
COTV flts/yr	11	22	42	0	0	0
HLLV flts/yr	7	13	22	3	5	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.19	0.27	0.36	1.00	1.42	1.85
Persnl consum, 10^3T/yr	0.27	0.55	0.93	1.77	3.62	6.13
HLLV flts/yr	1	2	3	6	12	21

TABLE VI-F-1 (CONT'D)

YEAR 2004 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	93.600	162.240	235.040	97.377	191.460	293.796
COTV flts/yr	312	649	1175	33	33	33
HLLV flts/yr	210	383	615	219	452	769
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	97.954	169.931	247.922	99.250	194.914	299.675
Total COTV flts/yr	327	680	1240	34	34	34
COTV prop wt, 10^3T/yr	187.42	390.16	711.54	26.42	55.29	115.18
COTV flt cost, $M/yr	555	1767	4834	1391	2981	4956
COTV fleet size, units	4	11	24	34	34	34
COTV replacement, units	0	2	26	0	0	0
HLLV flts/yr	447	977	1981	96	206	448
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	299.87	589.96	1015.22	145.75	289.38	483.10
Total HLLV flts/yr	674	1391	2658	328	682	1265
HLLV flt cost, $M/yr	4717	12523	37207	2293	6142	17705
HLLV fleet size, units	9	23	51	4	11	24
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	51	120	298	23	56	138
PLV flt cost, $M/yr	248	624	1461	315	794	1860
COTV flt cost, $M/yr	555	1767	4834	1391	2981	4956
Subtotal	853	2512	6593	1729	3832	6954
HLLV flt cost, $M/yr	4717	12523	37207	2293	6142	17705
TOTAL TRANSPORTATION COST $M	5571	15035	43800	4022	9974	24659
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

TABLE VI-F-1 (CONT'D)

YEAR 2005 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.100	2.100	2.100	2.100	2.100	2.100
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	94.500	163.800	237.300	98.314	193.301	296.621
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2129	3041	3952	987	1407	1831
POTV flts/yr	21	41	79	10	19	37
POTV prop wt, 10^3T/yr	3.45	6.57	12.81	1.60	3.04	5.93
POTV flt cost, $M/yr	51	122	300	24	56	139
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	17	36	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2453	3503	4553	3121	4456	5796
PLV flts/yr	25	47	91	31	59	116
PLV flt cost, $M/yr	250	631	1475	318	802	1878
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.40	1.82	2.37	0.46	0.66	0.86
Persnl consum, 10^3T/yr	1.79	3.65	6.17	0.83	1.69	2.86
COTV flts/yr	11	22	43	0	0	0
HLLV flts/yr	7	13	22	3	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.19	0.28	0.36	1.01	1.44	1.87
Persnl consum, 10^3T/yr	0.27	0.55	0.94	1.79	3.66	6.18
HLLV flts/yr	1	2	3	6	12	21

TABLE VI-F-1 (CONT'D)

YEAR 2005 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	94.500	163.800	237.300	98.314	193.301	296.621
COTV flts/yr	315	655	1187	34	34	34
HLLV flts/yr	212	386	621	221	456	776
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	98.896	171.565	250.305	100.205	196.788	302.557
Total COTV flts/yr	330	686	1252	34	34	34
COTV prop wt, 10^3T/yr	189.22	393.91	718.38	26.68	55.82	116.29
COTV flt cost, $M/yr	560	1784	4881	1404	3010	5004
COTV fleet size, units	5	11	24	34	34	34
COTV replacement, units	0	2	26	0	0	0
HLLV flts/yr	451	987	2000	97	208	452
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	302.76	595.63	1024.99	147.15	292.16	487.74
Total HLLV flts/yr	680	1405	2683	331	689	1277
HLLV flt cost, $M/yr	4762	12643	37565	2315	6202	17875
HLLV fleet size, units	9	23	51	5	11	24
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	51	122	300	24	56	139
PLV flt cost, $M/yr	250	631	1475	318	802	1878
COTV flt cost, $M/yr	560	1784	4881	1404	3010	5004
Subtotal	862	2536	6656	1746	3869	7021
HLLV flt cost, $M/yr	4762	12643	37565	2315	6202	17875
TOTAL TRANSPORTATION COST $M	5624	15179	44221	4061	10070	24896
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2006 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.120	2.120	2.120	2.120	2.120	2.120
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	95.400	165.360	239.560	99.250	195.142	299.446
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2150	3070	3990	996	1420	1849
POTV flts/yr	21	41	80	10	19	37
POTV prop wt, 10^3T/yr	3.48	6.63	12.93	1.61	3.07	5.99
POTV flt cost, \$M/yr	52	123	303	24	57	140
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	17	37	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2476	3536	4596	3150	4499	5851
PLV flts/yr	25	47	92	32	60	117
PLV flt cost, \$M/yr	253	637	1489	321	810	1896
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.42	1.84	2.39	0.47	0.67	0.87
Persnl consum, 10^3T/yr	1.81	3.68	6.22	0.84	1.70	2.88
COTV flts/yr	11	22	43	0	0	0
HLLV flts/yr	7	13	23	3	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.20	0.28	0.36	1.02	1.45	1.88
Persnl consum, 10^3T/yr	0.27	0.56	0.95	1.81	3.69	6.24
HLLV flts/yr	1	2	3	6	12	21

TABLE VI-F-1 (CONT'D)

YEAR 2006 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	95.400	165.360	239.560	99.250	195.142	299.446
COTV flts/yr	318	661	1198	34	34	34
HLLV flts/yr	214	390	627	223	460	784
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	99.838	173.199	252.689	101.159	198.663	305.438
Total COTV flts/yr	333	693	1263	35	35	35
COTV prop wt, 10^3T/yr	191.02	397.66	725.22	26.93	56.36	117.39
COTV flt cost, $M/yr	566	1801	4927	1417	3039	5051
COTV fleet size, units	5	11	24	35	35	35
COTV replacement, units	0	2	26	0	0	0
HLLV flts/yr	456	996	2019	97	210	456
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	305.64	601.30	1034.75	148.55	294.94	492.39
Total HLLV flts/yr	687	1418	2709	334	696	1289
HLLV flt cost, $M/yr	4808	12763	37923	2337	6261	18046
HLLV fleet size, units	9	23	52	5	11	25
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	52	123	303	24	57	140
PLV flt cost, $M/yr	252	637	1489	321	810	1896
COTV flt cost, $M/yr	566	1801	4927	1417	3039	5051
Subtotal	870	2561	6720	1763	3905	7088
HLLV flt cost, $M/yr	4808	12763	37923	2337	6261	18046
TOTAL TRANSPORTATION COST $M	5678	15324	44642	4099	10166	25133
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2007 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.140	2.140	2.140	2.140	2.140	2.140
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	96.300	166.920	241.820	100.186	196.983	302.271
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2170	3099	4027	1006	1434	1866
POTV flts/yr	22	41	81	10	19	37
POTV prop wt, 10^3T/yr	3.52	6.69	13.05	1.63	3.10	6.05
POTV flt cost, $M/yr	52	124	306	24	57	142
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	9	17	37	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2500	3570	4640	3180	4541	5906
PLV flts/yr	25	48	93	32	61	118
PLV flt cost, $M/yr	255	643	1503	324	817	1914
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.43	1.86	2.42	0.47	0.68	0.88
Persnl consum, 10^3T/yr	1.82	3.72	6.28	0.85	1.72	2.91
COTV flts/yr	11	22	43	0	0	0
HLLV flts/yr	7	13	23	3	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.20	0.28	0.37	1.03	1.46	1.90
Persnl consum, 10^3T/yr	0.28	0.56	0.95	1.83	3.73	6.30
HLLV flts/yr	1	2	3	6	12	21

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2007 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	96.300	166.920	241.820	100.186	196.983	302.271
COTV flts/yr	321	668	1209	34	34	34
HLLV flts/yr	216	394	633	225	465	791
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	100.780	174.833	255.073	102.113	200.537	308.320
Total COTV flts/yr	336	699	1275	35	35	35
COTV prop wt, 10^3T/yr	192.83	401.42	732.06	27.19	56.89	118.50
COTV flt cost, $M/yr	571	1818	4974	1431	3067	5099
COTV fleet size, units	5	11	24	35	35	35
COTV replacement, units	0	2	27	0	0	0
HLLV flts/yr	460	1006	2038	98	212	461
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	308.52	606.97	1044.51	149.95	297.73	497.03
Total HLLV flts/yr	693	1432	2734	337	702	1301
HLLV flt cost, $M/yr	4853	12884	38280	2359	6320	18216
HLLV fleet size, units	9	24	52	5	12	25
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	52	124	306	24	57	142
PLV flt cost, $M/yr	255	643	1503	324	817	1914
COTV flt cost, $M/yr	571	1818	4974	1431	3067	5099
Subtotal	878	2585	6783	1779	3942	7155
HLLV flt cost, $M/yr	4853	12884	38280	2359	6320	18216
TOTAL TRANSPORTATION COST $M	5731	15469	45064	4138	10262	25370
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2008 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	2.160	2.160	2.160	2.160	2.160	2.160
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	97.200	168.480	244.080	101.123	198.824	305.096
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2190	3128	4065	1015	1447	1884
POTV flts/yr	22	42	81	10	19	38
POTV prop wt, 10^3T/yr	3.55	6.76	13.17	1.64	3.13	6.10
POTV flt cost, $M/yr	53	125	309	24	58	143
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	9	17	37	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2523	3603	4683	3210	4584	5962
PLV flts/yr	25	48	94	32	61	119
PLV flt cost, $M/yr	257	649	1517	327	825	1932
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.44	1.87	2.44	0.48	0.68	0.89
Persnl consum, 10^3T/yr	1.84	3.75	6.34	0.85	1.74	2.94
COTV flts/yr	11	23	44	0	0	0
HLLV flts/yr	7	13	23	3	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.20	0.29	0.37	1.03	1.48	1.92
Persnl consum, 10^3T/yr	0.28	0.57	0.96	1.84	3.76	6.36
HLLV flts/yr	1	2	3	6	12	22

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2008 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	97.200	168.480	244.080	101.123	198.824	305.096
COTV flts/yr	324	674	1220	35	35	35
HLLV flts/yr	218	397	639	227	469	799
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	101.722	176.467	257.457	103.068	202.411	311.201
Total COTV flts/yr	339	706	1287	35	35	35
COTV prop wt, 10^3T/yr	194.63	405.17	738.90	27.44	57.42	119.61
COTV flt cost, $M/yr	576	1835	5020	1444	3096	5147
COTV fleet size, units	5	12	25	35	35	35
COTV replacement, units	0	3	27	0	0	0
HLLV flts/yr	464	1015	2057	99	214	465
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	311.41	612.65	1054.27	151.36	300.51	501.68
Total HLLV flts/yr	700	1445	2760	340	709	1313
HLLV flt cost, $M/yr	4899	13004	38638	2381	6379	18386
HLLV fleet size, units	10	24	53	5	12	25
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	53	125	309	24	58	143
PLV flt cost, $M/yr	257	649	1517	327	825	1932
COTV flt cost, $M/yr	576	1835	5020	1444	3096	5147
Subtotal	886	2609	6847	1796	3979	7221
HLLV flt cost, $M/yr	4899	13004	38638	2381	6379	18386
TOTAL TRANSPORTATION COST $M	5785	15613	45485	4177	10358	25607
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2009 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.180	2.180	2.180	2.180	2.180	2.180
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	98.100	170.040	246.340	102.059	200.665	307.921
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2211	3157	4103	1025	1461	1901
POTV flts/yr	22	42	82	10	19	38
POTV prop wt, 10^3T/yr	3.58	6.82	13.29	1.66	3.15	6.16
POTV flt cost, $M/yr	53	126	312	25	58	144
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	9	17	38	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2546	3636	4726	3239	4626	6017
PLV flts/yr	25	48	95	32	62	120
PLV flt cost, $M/yr	260	655	1531	330	833	1949
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.46	1.89	2.46	0.48	0.69	0.90
Persnl consum, 10^3T/yr	1.86	3.79	6.40	0.86	1.75	2.96
COTV flts/yr	11	23	44	0	0	0
HLLV flts/yr	7	13	23	3	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.20	0.29	0.37	1.04	1.49	1.94
Persnl consum, 10^3T/yr	0.28	0.58	0.97	1.86	3.80	6.42
HLLV flts/yr	1	2	4	7	12	22

TABLE VI-F-1 (CONT'D)

YEAR 2009 TRANSPORTATION TRAFFIC MODEL
(*Preliminary Estimates*)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	98.100	170.040	246.340	102.059	200.665	307.921
COTV flts/yr	327	680	1232	35	35	35
HLLV flts/yr	220	401	645	229	473	806
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	102.663	178.101	259.841	104.022	204.285	314.083
Total COTV flts/yr	342	712	1299	36	36	36
COTV prop wt, 10^3T/yr	196.43	408.92	745.74	27.69	57.95	120.72
COTV flt cost, $M/yr	582	1852	5067	1458	3125	5194
COTV fleet size, units	5	12	25	36	36	36
COTV replacement, units	0	3	27	0	0	0
HLLV flts/yr	469	1024	2076	100	216	469
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	314.29	618.32	1064.03	152.76	303.29	506.32
Total HLLV flts/yr	706	1458	2785	343	715	1325
HLLV flt cost, $M/yr	4944	13125	38996	2403	6438	18556
HLLV fleet size, units	10	24	53	5	12	25
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	53	126	312	25	58	144
PLV flt cost, $M/yr	260	655	1531	330	833	1949
COTV flt cost, $M/yr	582	1852	5067	1458	3125	5194
Subtotal	895	2633	6910	1813	4016	7288
HLLV flt cost, $M/yr	4944	13125	38996	2403	6438	18556
TOTAL TRANSPORTATION COST $M	58[illegible]8	15758	45906	4216	10454	25845
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario A'

TABLE VI-F-1 (CONT'D)

YEAR 2010 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	2.200	2.200	2.200	2.200	2.200	2.200
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	99.000	171.600	248.600	102.995	202.506	310.746
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2231	3186	4140	1034	1474	1918
POTV flts/yr	22	42	83	10	20	38
POTV prop wt, 10^3T/yr	3.61	6.88	13.41	1.68	3.18	6.22
POTV flt cost, \$M/yr	54	127	315	25	59	146
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	9	18	38	4	8	18
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2570	3670	4770	3269	4668	6072
PLV flts/yr	26	49	95	33	62	121
PLV flt cost, \$M/yr	262	661	1545	333	840	1967
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.47	1.91	2.48	0.49	0.70	0.90
Persnl consum, 10^3T/yr	1.87	3.82	6.46	0.87	1.77	2.99
COTV flts/yr	11	25	45	0	0	0
HLLV flts/yr	8	14	23	3	6	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.20	0.29	0.38	1.05	1.50	1.96
Persnl consum, 10^3T/yr	0.28	0.58	0.98	1.88	3.83	6.48
HLLV flts/yr	1	2	4	7	13	22

TABLE VI-F-1 (CONT'D)

YEAR 2010 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	99.000	171.600	248.600	102.995	202.506	310.746
COTV flts/yr	330	686	1243	35	35	35
HLLV flts/yr	222	405	651	231	478	813
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	103.605	179.735	262.225	104.976	206.159	316.964
Total COTV flts/yr	345	719	1311	36	36	36
COTV prop wt, 10^3T/yr	198.23	412.67	752.59	27.95	58.48	121.82
COTV flt cost, $M/yr	587	1869	5113	1471	3153	5242
COTV fleet size, units	5	12	25	36	36	36
COTV replacement, units	0	3	27	0	0	0
HLLV flts/yr	473	1034	2095	101	218	474
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	317.17	623.99	1073.79	154.16	306.07	510.97
Total HLLV flts/yr	713	1472	2811	346	722	1338
HLLV flt cost, $M/yr	4989	13245	39354	2425	6497	18727
HLLV fleet size, units	10	24	54	5	12	26
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	54	127	315	25	59	146
PLV flt cost, $M/yr	262	661	1545	333	840	1967
COTV flt cost, $M/yr	587	1869	5113	1471	3153	5242
Subtotal	903	2657	6973	1829	4053	7355
HLLV flt cost, $M/yr	4989	13245	39354	2425	6497	18727
TOTAL TRANSPORTATION COST $M	5892	15902	46327	4254	10550	26082
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2
YEAR 1995 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates) (Typical of Base Instll. yrs.)

6/20/77

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	1.0	1.0	1.0	1.0	1.0	1.0
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
GEO persnl/SPS	507	724	941	235	335	436
GEO persnl consum/SPS, 10^3T	0.852	1.738	2.936	0.395	0.804	1.360
GEO Base, 10^3T	3.000	6.000	9.000	0.750	1.000	1.250
GEO Base equip&consum/SPS, 10^3T	0.668	0.868	1.129	0.221	0.316	0.411
LEO persnl/SPS	77	110	143	508	726	944
LEO persnl consum/SPS, 10^3T	0.129	0.264	0.446	0.853	1.742	2.945
LEO Base, 10^3T	0.750	1.000	1.250	3.000	6.000	9.000
LEO Base equip&consum/SPS, 10^3T	0.092	0.132	0.171	0.479	0.684	0.889
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	2.926	5.753	8.828
Total inert wt, 10^3T	0.036	0.036	0.036	0.422	0.829	1.413
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	0.779	1.632	3.393
Flt cost, $M/flt	1.7	2.6	3.9	41.0	88.0	146.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, $M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 1995 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.000	1.000	1.000	1.000	1.000	1.000
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1014	1448	1882	470	670	872
POTV flts/yr	10	19	38	5	9	17
POTV prop wt, 10^3T/yr	1.64	3.13	6.10	0.76	1.45	2.83
POTV flt cost, \$M/yr	24	58	143	11	27	66
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	17	2	4	8
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1168	1668	2168	1486	2122	2760
PLV flts/yr	12	22	43	15	28	55
PLV flt cost, \$M/yr	119	300	702	152	382	894
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	0.67	0.87	1.13	0.22	0.32	0.41
Persnl consum, 10^3T/yr	0.85	1.74	2.94	0.40	0.80	1.36
COTV flts/yr	15	34	65	0	0	0
HLLV flts/yr	10	20	34	3	5	8
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.09	0.13	0.17	0.48	0.68	0.89
Persnl consum, 10^3T/yr	0.1[illegible]	0.26	0.45	0.85	1.74	2.95
HLLV flts/yr	[illegible]	3	5	10	20	34

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 1995 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	45.000	78.000	113.000	46.816	92.048	141.248
COTV flts/yr	150	312	565	16	16	16
HLLV flts/yr	101	184	296	105	217	370
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	50.093	87.698	128.193	48.448	94.673	145.255
Total COTV flts/yr	167	351	641	17	16	16
COTV prop wt, 10^3T/yr	95.85	201.35	367.91	12.90	26.86	55.83
COTV flt cost, $M/yr	284	912	2500	679	1448	2402
COTV fleet size, units	2	6	12	17	16	16
COTV replacement, units	0	1	13	0	0	0
HLLV flts/yr	229	504	1024	46	99	216
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	154.01	305.27	525.81	74.01	146.29	242.64
Total HLLV flts/yr	346	720	1376	166	345	635
HLLV flt cost, $M/yr	2423	6480	19270	1164	3105	8893
HLLV fleet size, units	5	12	26	2	6	12
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	24	58	143	11	27	66
PLV flt cost, $M/yr	119	300	702	152	382	894
COTV flt cost, $M/yr	284	912	2500	679	1448	2402
Subtotal	427	1270	3345	842	1857	3363
HLLV flt cost, $M/yr	2423	6480	19270	1164	3105	8893
TOTAL TRANSPORTATION COST $M	2850	7750	22616	2006	4962	12255
Specific cost, $/Kg SPS	63.[illegible]	99.36	200.14	42.85	53.91	86.77

Construction + Repair
Scenario C'

TABL I-F-2 (CONT'D)
YEAR 1996 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates) (Typical of non-Base Instll. yrs.)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.0	1.0	1.0	1.0	1.0	1.0
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
GEO persnl/SPS	507	724	941	235	335	436
GEO persnl consum/SPS, 10^3T	0.852	1.738	2.936	0.395	0.804	1.360
GEO Base, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
GEO Base equip&consum/SPS, 10^3T	0.668	0.868	1.129	0.221	0.316	0.411
LEO persnl/SPS	77	110	143	508	726	944
LEO persnl consum/SPS, 10^3T	0.129	0.264	0.446	0.853	1.742	2.945
LEO Base, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
LEO Base equip&consum/SPS, 10^3T	0.092	0.132	0.171	0.479	0.684	0.889
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	2.926	5.753	8.828
Total inert wt, 10^3T	0.036	0.036	0.036	0.422	0.829	1.413
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	0.779	1.632	3.393
Flt cost, $M/flt	1.7	2.6	3.9	41.0	88.0	146.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, $M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

TABLE VI-F-2 (CONT'D)

YEAR 1996 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	1.010	1.010	1.010	1.010	1.010	1.010
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	45.450	78.780	114.130	47.284	92.968	142.660
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1024	1462	1901	475	677	881
POTV flts/yr	10	19	38	5	9	18
POTV prop wt, 10^3T/yr	1.66	3.16	6.16	0.77	1.46	2.85
POTV flt cost, $M/yr	25	58	144	11	27	67
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	17	2	4	8
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1180	1685	2190	1501	2143	2788
PLV flts/yr	12	22	44	15	29	56
PLV flt cost, $M/yr	120	303	709	153	386	903
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.67	0.88	1.14	0.22	0.32	0.42
Persnl consum, 10^3T/yr	0.86	1.76	2.97	0.40	0.81	1.37
COTV flts/yr	5	11	21	0	0	0
HLLV flts/yr	3	6	11	1	3	5
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.09	0.13	0.17	0.48	0.69	0.90
Persnl consum, 10^3T/yr	0.13	0.27	0.45	0.86	1.76	2.97
HLLV flts/yr	1	1	2	3	6	10

TABLE VI-F-2 (CONT'D)

YEAR 1996 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	45.450	78.780	114.130	47.284	92.968	142.660
COTV flts/yr	152	315	571	16	16	16
HLLV flts/yr	102	186	299	106	219	373
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	47.564	82.515	120.385	48.194	94.646	145.515
Total COTV flts/yr	159	330	602	16	16	16
COTV prop wt, 10^3T/yr	91.01	189.45	345.51	12.83	26.85	55.93
COTV flt cost, $M/yr	270	858	2348	675	1448	2407
COTV fleet size, units	2	5	12	16	16	16
COTV replacement, units	0	1	13	0	0	0
HLLV flts/yr	217	475	962	46	100	217
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	145.61	286.47	492.97	70.77	140.52	234.58
Total HLLV flts/yr	327	676	1290	159	331	614
HLLV flt cost, $M/yr	2291	6081	18067	1113	2983	8597
HLLV fleet size, units	4	11	25	2	5	12
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	25	58	144	11	27	67
PLV flt cost, $M/yr	120	303	709	153	386	903
COTV flt cost, $M/yr	270	858	2348	675	1448	2407
Subtotal	414	1220	3201	840	1861	3377
HLLV flt cost, $M/yr	2291	6081	18067	1113	2983	8597
TOTAL TRANSPORTATION COST $M	2705	7301	21268	1953	4843	11974
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 1997 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.020	1.020	1.020	1.020	1.020	1.020
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	45.900	79.560	115.260	47.752	93.889	144.073
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1034	1477	1920	479	683	889
POTV flts/yr	10	20	38	5	9	18
POTV prop wt, 10^3T/yr	1.68	3.19	6.22	0.78	1.48	2.88
POTV flt cost, $M/yr	25	59	146	12	27	68
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	18	2	4	8
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1191	1701	2211	1516	2164	2815
PLV flts/yr	12	23	44	15	29	56
PLV flt cost, $M/yr	122	306	716	155	390	912
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.68	0.89	1.15	0.23	0.32	0.42
Persnl consum, 10^3T/yr	0.87	1.77	2.99	0.40	0.82	1.39
COTV flts/yr	5	11	21	0	0	0
HLLV flts/yr	3	6	11	1	3	5
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.09	0.13	0.17	0.49	0.70	0.91
Persnl consum, 10^3T/yr	0.13	0.27	0.45	0.87	1.78	3.00
HLLV flts/yr	1	1	2	3	6	10

TABLE VI-F-2 (CONT'D)

YEAR 1997 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	45.900	79.560	115.260	47.752	93.889	144.073
COTV flts/yr	153	318	576	16	16	16
HLLV flts/yr	103	188	302	107	221	377
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	48.035	83.332	121.577	48.671	95.583	146.956
Total COTV flts/yr	160	333	608	17	17	17
COTV prop wt, 10^3T/yr	91.91	191.33	348.93	12.96	27.11	56.48
COTV flt cost, $M/yr	272	867	2371	682	1462	2430
COTV fleet size, units	2	5	12	17	17	17
COTV replacement, units	0	1	13	0	0	0
HLLV flts/yr	219	479	971	47	101	220
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	147.05	289.31	497.85	71.47	141.91	236.90
Total HLLV flts/yr	330	682	1303	161	335	620
HLLV flt cost, $M/yr	2313	6141	18246	1124	3012	8682
HLLV fleet size, units	5	11	25	2	6	12
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	25	59	146	12	27	68
PLV flt cost, $M/yr	122	306	716	155	390	912
COTV flt cost, $M/yr	272	867	2371	682	1462	2430
Subtotal	419	1232	3233	848	1879	3410
HLLV flt cost, $M/yr	2313	6141	18246	1124	3012	8682
TOTAL TRANSPORTATION COST $M	2732	7373	21479	1972	4891	12092
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

TABLE VI-F-2 (CONT'D)

YEAR 1998 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.030	1.030	1.030	1.030	1.030	1.030
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	46.350	80.340	116.390	48.220	94.809	145.485
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1044	1491	1938	484	690	898
POTV flts/yr	10	20	39	5	9	18
POTV prop wt, 10^3T/yr	1.69	3.22	6.28	0.78	1.49	2.91
POTV flt cost, $M/yr	25	60	147	12	28	68
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	4	8	18	2	4	8
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1203	1718	2233	1531	2186	2843
PLV flts/yr	12	23	45	15	29	57
PLV flt cost, $M/yr	123	309	724	156	393	921
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	0.69	0.89	1.16	0.23	0.33	0.42
Persnl consum, 10^3T/yr	0.88	1.79	3.02	0.41	0.83	1.40
COTV flts/yr	15	35	66	0	0	0
HLLV flts/yr	10	20	35	3	5	8
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.09	0.14	0.18	0.49	0.70	0.92
Persnl consum, 10^3T/yr	0.13	0.27	0.46	0.88	1.79	3.03
HLLV flts/yr	2	3	5	10	20	34

TABLE VI-F-2 (CONT'D)

YEAR 1998 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3 T/yr	46.350	80.340	116.390	48.220	94.809	145.485
COTV flts/yr	155	321	582	16	16	16
HLLV flts/yr	104	189	305	108	224	381
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	51.506	90.148	131.769	49.898	97.520	149.647
Total COTV flts/yr	172	361	659	17	17	17
COTV prop wt, 10^3 T/yr	98.55	206.98	378.18	13.28	27.66	57.52
COTV flt cost, $M/yr	292	938	2569	699	1492	2475
COTV fleet size, units	2	6	13	17	17	17
COTV replacement, units	0	1	14	0	0	0
HLLV flts/yr	235	519	1053	48	103	224
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	158.34	313.78	540.45	76.25	150.74	250.19
Total HLLV flts/yr	356	740	1415	171	356	655
HLLV flt cost, $M/yr	2491	6660	19807	1199	3200	9169
HLLV fleet size, units	5	12	27	2	6	13
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	25	60	147	12	28	68
PLV flt cost, $M/yr	123	309	724	156	393	921
COTV flt cost, $M/yr	292	938	2569	699	1492	2475
Subtotal	440	1306	3440	867	1913	3464
HLLV flt cost, $M/yr	2491	6660	19807	1199	3200	9169
TOTAL TRANSPORTATION COST $M	2930	7967	23247	2066	5112	12633
Specific cost, $/Kg SPS	63.[illegible]	99.16	199.74	42.85	53.92	86.84

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 1999 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.040	2.040	2.040	2.040	2.040	2.040
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	91.800	159.120	230.520	95.505	187.778	288.146
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2069	2954	3839	959	1367	1779
POTV flts/yr	21	39	77	10	18	36
POTV prop wt, 10^3T/yr	3.35	6.38	12.44	1.55	2.95	5.76
POTV flt cost, $M/yr	50	118	292	23	55	135
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	16	35	4	8	16
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2383	3403	4423	3031	4329	5630
PLV flts/yr	24	45	88	30	58	113
PLV flt cost, $M/yr	243	612	1433	309	779	1824
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.36	1.77	2.30	0.45	0.64	0.84
Persnl consum, 10^3T/yr	1.74	3.55	5.99	0.81	1.64	2.77
COTV flts/yr	10	21	41	0	0	0
HLLV flts/yr	7	13	22	3	5	9
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.19	0.27	0.35	0.98	1.40	1.81
Persnl consum, 10^3T/yr	0.26	0.54	0.91	1.74	3.55	6.01
HLLV flts/yr	1	2	3	6	12	20

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 1999 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	91.800	159.120	230.520	95.505	187.778	288.146
COTV flts/yr	306	636	1153	33	33	33
HLLV flts/yr	206	375	603	215	443	754
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	96.070	166.663	243.154	97.303	191.093	293.770
Total COTV flts/yr	320	667	1216	33	33	33
COTV prop wt, 10^3T/yr	183.81	382.66	697.85	25.91	54.21	112.91
COTV flt cost, $M/yr	544	1733	4742	1363	2923	4858
COTV fleet size, units	4	11	23	33	33	33
COTV replacement, units	0	2	25	0	0	0
HLLV flts/yr	439	959	1943	93	201	437
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	294.11	578.61	995.70	142.67	283.25	472.63
Total HLLV flts/yr	661	1365	2607	321	668	1237
HLLV flt cost, $M/yr	4626	12282	36492	2244	6012	17322
HLLV fleet size, units	9	22	50	4	11	24
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	50	118	292	23	55	135
PLV flt cost, $M/yr	243	612	1433	309	779	1824
COTV flt cost, $M/yr	544	1733	4742	1363	2923	4858
Subtotal	837	2464	6466	1696	3757	6818
HLLV flt cost, $M/yr	4626	12282	36492	2244	6012	17322
TOTAL TRANSPORTATION COST $M	5463	14746	42958	3940	9769	24140
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.25	52.03	83.78

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Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2000 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.060	2.060	2.060	2.060	2.060	2.060
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	92.700	160.680	232.780	96.441	189.619	290.971
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2089	2983	3877	968	1380	1796
POTV flts/yr	21	40	78	10	18	36
POTV prop wt, 10^3T/yr	3.38	6.44	12.56	1.57	2.98	5.82
POTV flt cost, $M/yr	50	119	295	23	55	137
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	16	36	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2406	3436	4466	3061	4371	5686
PLV flts/yr	24	46	89	31	58	114
PLV flt cost, $M/yr	245	618	1447	312	787	1842
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.38	1.79	2.33	0.46	0.65	0.85
Persnl consum, 10^3T/yr	1.76	3.58	6.05	0.81	1.66	2.80
COTV flts/yr	10	21	42	0	0	0
HLLV flts/yr	7	13	22	3	5	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.19	0.27	0.35	0.99	1.41	1.83
Persnl consum, 10^3T/yr	0.27	0.54	0.92	1.76	3.59	6.07
HLLV flts/yr	1	2	3	6	12	21

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2000 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3 T/yr	92.700	160.680	232.780	96.441	189.619	290.971
COTV flts/yr	309	643	1164	33	33	33
HLLV flts/yr	208	379	609	217	447	762
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	97.012	168.297	245.538	98.296	193.040	296.794
Total COTV flts/yr	323	673	1228	34	34	34
COTV prop wt, 10^3 T/yr	185.62	386.41	704.69	26.17	54.76	114.07
COTV flt cost, $M/yr	550	1750	4788	1377	2953	4908
COTV fleet size, units	4	11	23	34	33	34
COTV replacement, units	0	2	26	0	0	0
HLLV flts/yr	443	968	1962	95	204	444
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	296.99	584.28	1005.46	144.35	286.60	478.45
Total HLLV flts/yr	667	1378	2632	324	676	1252
HLLV flt cost, $M/yr	4672	12402	36849	2271	6083	17535
HLLV fleet size, units	9	23	50	4	11	24
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	50	119	295	23	55	137
PLV flt cost, $M/yr	245	618	1447	312	787	1842
COTV flt cost, $M/yr	550	1750	4788	1377	2953	4908
Subtotal	845	2488	6530	1713	3795	6887
HLLV flt cost, $M/yr	4672	12402	36849	2271	6083	17535
TOTAL TRANSPORTATION COST $M	5517	14890	43379	3983	9878	24422
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2001 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.080	2.080	2.080	2.080	2.080	2:080
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	93.600	162.240	235.040	97.377	191.460	293.796
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2109	3012	3915	978	1394	1814
POTV flts/yr	21	40	78	10	19	36
POTV prop wt, 10^3T/yr	3.42	6.51	12.68	1.58	3.01	5.88
POTV flt cost, $M/yr	51	120	298	23	56	138
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	17	36	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2429	3469	4509	3091	4414	5741
PLV flts/yr	24	46	90	31	59	115
PLV flt cost, $M/yr	248	624	1461	315	794	1860
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.39	1.81	2.35	0.46	0.66	0.85
Persnl consum, 10^3T/yr	1.77	3.62	6.11	0.82	1.67	2.83
COTV flts/yr	11	22	42	0	0	0
HLLV flts/yr	7	13	22	3	5	10
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.19	0.27	0.36	1.00	1.42	1.85
Persnl consum, 10^3T/yr	0.27	0.55	0.93	1.77	3.62	6.13
HLLV flts/yr	1	2	3	6	12	21

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2001 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	93.600	162.240	235.040	97.377	191.460	293.796
COTV flts/yr	312	649	1175	33	33	33
HLLV flts/yr	210	383	615	219	452	769
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	97.954	169.931	247.922	99.250	194.914	299.675
Total COTV flts/yr	327	680	1240	34	34	34
COTV prop wt, 10^3T/yr	187.42	390.16	711.54	26.42	55.29	115.18
COTV flt cost, $M/yr	555	1767	4834	1391	2981	4956
COTV fleet size, units	4	11	24	34	34	34
COTV replacement, units	0	2	26	0	0	0
HLLV flts/yr	447	977	1981	96	206	448
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	299.87	589.96	1015.22	145.75	289.38	483.10
Total HLLV flts/yr	674	1391	2658	328	682	1265
HLLV flt cost, $M/yr	4717	12523	37207	2293	6142	17705
HLLV fleet size, units	9	23	51	4	11	24
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	51	120	298	23	56	138
PLV flt cost, $M/yr	248	624	1461	315	794	1860
COTV flt cost, $M/yr	555	1767	4834	1391	2981	4956
Subtotal	853	2512	6593	1729	3832	6954
HLLV flt cost, $M/yr	4717	12523	37207	2293	6142	17705
TOTAL TRANSPORTATION COST $M	5571	15035	43800	4022	9974	24659
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2002 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	2.100	2.100	2.100	2.100	2.100	2.100
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	94.500	163.800	237.300	98.314	193.301	296.621
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2129	3041	3952	987	1407	1831
POTV flts/yr	21	41	79	10	19	37
POTV prop wt, 10^3T/yr	3.45	6.57	12.81	1.60	3.04	5.93
POTV flt cost, $M/yr	51	122	300	24	56	139
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	1	0	0	0
HLLV flts/yr	8	17	36	4	8	17
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2453	3503	4553	3121	4456	5796
PLV flts/yr	25	47	91	31	59	116
PLV flt cost, $M/yr	250	631	1475	318	802	1878
PLV fleet size, units	2	2	3	2	2	4
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	1.40	1.82	2.37	0.46	0.66	0.86
Persnl consum, 10^3T/yr	1.79	3.65	6.17	0.83	1.69	2.86
COTV flts/yr	21	46	88	1	1	1
HLLV flts/yr	14	27	46	5	8	13
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.19	0.28	0.36	1.01	1.44	1.87
Persnl consum, 10^3T/yr	0.27	0.55	0.94	1.79	3.66	6.18
HLLV flts/yr	3	4	7	13	26	45

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2002 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	94.500	163.800	237.300	98.314	193.301	296.621
COTV flts/yr	315	655	1187	34	34	34
HLLV flts/yr	212	386	621	221	456	776
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	101.896	177.565	259.305	100.955	197.788	303.807
Total COTV flts/yr	340	710	1297	35	34	34
COTV prop wt, 10^3T/yr	194.96	407.69	744.21	26.88	56.11	116.77
COTV flt cost, $M/yr	577	1847	5056	1415	3025	5024
COTV fleet size, units	5	12	25	35	34	34
COTV replacement, units	0	3	27	0	0	0
HLLV flts/yr	465	1021	2072	97	209	454
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	312.60	617.26	1062.71	151.22	299.61	498.70
Total HLLV flts/yr	702	1456	2782	340	707	1306
HLLV flt cost, $M/yr	4917	13102	38947	2379	6360	18277
HLLV fleet size, units	10	24	53	5	12	25
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	51	122	300	24	56	139
PLV flt cost, $M/yr	250	631	1475	318	802	1878
COTV flt cost, $M/yr	577	1847	5056	1415	3025	5024
Subtotal	879	2599	6832	1757	3884	7042
HLLV flt cost, $M/yr	4917	13102	38947	2379	6360	18277
TOTAL TRANSPORTATION COST $M	5796	15701	45779	4135	10243	25319
Specific cost, $/Kg SPS	61.33	95.86	192.92	42.06	52.99	85.36

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2003 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	3.120	3.120	3.120	3.120	3.120	3.120
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	140.400	243.360	352.560	146.066	287.190	440.694
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	3164	4518	5872	1466	2090	2721
POTV flts/yr	32	60	117	15	28	54
POTV prop wt, 10^3T/yr	5.13	9.76	19.02	2.38	4.52	8.81
POTV flt cost, $M/yr	76	181	446	35	84	207
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	2	0	0	0
HLLV flts/yr	12	25	54	6	12	26
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	3644	5204	6764	4636	6621	8611
PLV flts/yr	36	69	135	46	88	172
PLV flt cost, $M/yr	372	937	2192	473	1192	2790
PLV fleet size, units	2	2	5	2	3	6
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	2.08	2.71	3.52	0.69	0.99	1.28
Persnl consum, 10^3T/yr	2.66	5.42	9.16	1.23	2.51	4.24
COTV flts/yr	16	33	63	1	1	1
HLLV flts/yr	11	19	33	4	8	14
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.29	0.41	0.53	1.49	2.13	2.77
Persnl consum, 10^3T/yr	0.40	0.82	1.39	2.66	5.44	9.19
HLLV flts/yr	2	3	5	9	18	31

TABLE VI-F-2 (CONT'D)

YEAR 2003 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	140.400	243.360	352.560	146.066	287.190	440.694
COTV flts/yr	468	973	1763	50	50	50
HLLV flts/yr	316	574	923	328	677	1154
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	146.931	254.896	371.882	148.876	292.371	449.513
Total COTV flts/yr	490	1020	1859	51	51	51
COTV prop wt, 10^3T/yr	281.13	585.24	1067.30	39.64	82.94	172.77
COTV flt cost, $M/yr	833	2651	7252	2086	4472	7434
COTV fleet size, units	7	17	36	51	51	51
COTV replacement, units	0	4	39	0	0	0
HLLV flts/yr	671	1466	2971	143	308	672
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	449.81	884.93	1522.84	218.62	434.07	724.64
Total HLLV flts/yr	1011	2087	3986	491	1024	1897
HLLV flt cost, $M/yr	7076	18784	55811	3439	9214	26558
HLLV fleet size, units	14	34	76	7	17	36
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	76	181	446	35	84	207
PLV flt cost, $M/yr	372	937	2192	473	1192	2790
COTV flt cost, $M/yr	833	2651	7252	2086	4472	7434
Subtotal	1280	3768	9890	2594	5748	10431
HLLV flt cost, $M/yr	7076	18784	55811	3439	9214	26558
TOTAL TRANSPORTATION COST $M	8356	22552	65700	6033	14961	36989
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2004 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	3.150	3.150	3.150	3.150	3.150	3.150
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	141.750	245.700	355.950	147.470	289.951	444.931
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	3194	4561	5928	1481	2111	2747
POTV flts/yr	32	61	119	15	28	55
POTV prop wt, 10^3T/yr	5.17	9.85	19.21	2.40	4.56	8.90
POTV flt cost, $M/yr	77	182	451	36	84	209
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	2	0	0	0
HLLV flts/yr	13	25	54	6	12	26
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	3679	5254	6829	4681	6684	8694
PLV flts/yr	37	70	137	47	89	174
PLV flt cost, $M/yr	375	946	2213	477	1203	2817
PLV fleet size, units	2	2	5	2	3	6
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	2.10	2.73	3.56	0.70	1.00	1.29
Persnl consum, 10^3T/yr	2.68	5.47	9.25	1.24	2.53	4.28
COTV flts/yr	26	57	109	1	1	1
HLLV flts/yr	18	34	57	6	11	18
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.29	0.42	0.54	1.51	2.15	2.80
Persnl consum, 10^3T/yr	0.41	0.83	1.40	2.69	5.49	9.28
HLLV flts/yr	[illegible]	5	8	16	32	55

TABLE VI-F-2 (CONT'D)

YEAR 2004 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3 T/yr	141.750	245.700	355.950	147.470	289.951	444.931
COTV flts/yr	473	983	1780	50	50	50
HLLV flts/yr	319	579	932	331	684	1165
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	151.344	263.347	384.458	151.057	296.183	455.085
Total COTV flts/yr	504	1053	1922	52	51	52
COTV prop wt, 10^3 T/yr	289.57	604.65	1103.40	40.22	84.02	174.91
COTV flt cost, \$M/yr	858	2739	7497	2117	4531	7526
COTV fleet size, units	7	17	37	51	51	51
COTV replacement, units	0	4	40	0	0	0
HLLV flts/yr	691	1515	3072	146	312	680
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	463.98	915.08	1575.20	224.80	445.69	742.57
Total HLLV flts/yr	1043	2158	4124	505	1051	1944
HLLV flt cost, \$M/yr	7299	19424	57730	3536	9460	27215
HLLV fleet size, units	14	35	79	7	17	37
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, \$M/yr	77	182	451	36	84	209
PLV flt cost, \$M/yr	375	946	2213	477	1203	2817
COTV flt cost, \$M/yr	858	2739	7497	2117	4531	7526
Subtotal	1310	3867	10160	2630	5818	10552
HLLV flt cost, \$M/yr	7299	19424	57730	3536	9460	27215
TOTAL TRANSPORTATION COST \$M	8608	23291	67890	6166	15278	37767
Specific cost, \$/Kg SPS	60.73	94.79	190.73	41.81	52.69	84.88

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2005 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	4.180	4.180	4.180	4.180	4.180	4.180
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	188.100	326.040	472.340	195.691	384.761	590.417
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	4239	6053	7867	1965	2801	3645
POTV flts/yr	42	81	157	20	37	73
POTV prop wt, 10^3T/yr	6.87	13.07	25.49	3.18	6.05	11.81
POTV flt cost, $M/yr	102	242	598	47	112	277
POTV fleet size, units	2	2	3	2	2	2
POTV replacement, units	0	0	3	0	0	1
HLLV flts/yr	17	33	72	8	16	34
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	4882	6972	9062	6211	8870	11537
PLV flts/yr	49	93	181	62	118	231
PLV flt cost, $M/yr	498	1255	2936	634	1597	3738
PLV fleet size, units	2	3	6	2	4	8
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	2.79	3.63	4.72	0.92	1.32	1.72
Persnl consum, 10^3T/yr	3.56	7.26	12.27	1.65	3.36	5.68
COTV flts/yr	21	44	85	1	1	1
HLLV flts/yr	14	26	44	6	11	19
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.38	0.55	0.71	2.00	2.86	3.72
Persnl consum, 10^3T/yr	0.54	1.10	1.86	3.57	7.28	12.31
HLLV flts/yr	2	4	7	13	24	42

TABLE VI-F-2 (CONT'D)

YEAR 2005 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	188.100	326.040	472.340	195.691	384.761	590.417
COTV flts/yr	627	1304	2362	67	67	67
HLLV flts/yr	423	769	1236	440	907	1546
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	196.850	341.496	498.227	199.455	391.703	602.232
Total COTV flts/yr	656	1366	2491	68	68	68
COTV prop wt, 10^3T/yr	376.64	784.07	1429.91	53.10	111.12	231.47
COTV flt cost, $M/yr	1115	3552	9715	2795	5992	9960
COTV fleet size, units	9	22	48	68	68	68
COTV replacement, units	0	5	52	0	0	0
HLLV flts/yr	899	1964	3981	192	413	900
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	602.63	1185.58	2040.21	292.90	581.54	970.84
Total HLLV flts/yr	1354	2796	5341	658	1372	2541
HLLV flt cost, $M/yr	9480	25166	74772	4607	12344	35580
HLLV fleet size, units	19	46	102	9	23	49
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	102	242	598	47	112	277
PLV flt cost, $M/yr	498	1255	2936	634	1597	3738
COTV flt cost, $M/yr	1115	3552	9715	2795	5992	9960
Subtotal	1715	5049	13249	3476	7700	13975
HLLV flt cost, $M/yr	9480	25166	74772	4607	12344	35580
TOTAL TRANSPORTATION COST $M	11195	30214	88022	8083	20044	49555
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2006 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	4.220	4.220	4.220	4.220	4.220	4.220
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	189.900	329.160	476.860	197.564	388.443	596.067
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	4279	6111	7942	1983	2827	3680
POTV flts/yr	43	81	159	20	38	74
POTV prop wt, 10^3T/yr	6.93	13.20	25.73	3.21	6.11	11.92
POTV flt cost, \$M/yr	103	244	604	48	113	280
POTV fleet size, units	2	2	3	2	2	2
POTV replacement, units	0	0	3	0	0	1
HLLV flts/yr	17	34	73	8	16	34
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	4929	7039	9149	6271	8955	11647
PLV flts/yr	49	94	183	63	119	233
PLV flt cost, \$M/yr	503	1267	2964	640	1612	3774
PLV fleet size, units	2	3	7	2	4	8
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	3.00	6.00	9.00	0.75	1.00	1.25
Equip & consum, 10^3T/yr	2.82	3.66	4.76	0.93	1.33	1.73
Persnl consum, 10^3T/yr	3.60	7.33	12.39	1.67	3.39	5.74
COTV flts/yr	31	68	131	1	1	1
HLLV flts/yr	21	40	68	8	14	23
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.75	1.00	1.25	3.00	6.00	9.00
Equip & consum, 10^3T/yr	0.39	0.56	0.72	2.02	2.89	3.75
Persnl consum, 10^3T/yr	0.54	1.11	1.88	3.60	7.35	12.43
HLLV flts/yr	4	6	10	19	38	66

TABLE VI-F-2 (CONT'D)

YEAR 2006 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	189.900	329.160	476.860	197.564	388.443	596.067
COTV flts/yr	633	1317	2384	68	68	68
HLLV flts/yr	427	776	1248	444	916	1560
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	201.734	350.764	511.995	202.034	396.300	608.951
Total COTV flts/yr	672	1403	2560	69	69	69
COTV prop wt, 10^3T/yr	385.98	805.35	1469.43	53.79	112.42	234.05
COTV flt cost, $M/yr	1143	3648	9984	2831	6062	10071
COTV fleet size, units	9	23	49	69	69	69
COTV replacement, units	0	5	53	0	0	0
HLLV flts/yr	921	2018	4091	194	416	905
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	618.24	1218.56	2097.45	299.21	593.38	988.66
Total HLLV flts/yr	1389	2874	5491	672	1399	2588
HLLV flt cost, $M/yr	9725	25866	76870	4707	12595	36234
HLLV fleet size, units	19	47	105	9	23	50
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	103	244	604	48	113	280
PLV flt cost, $M/yr	503	1267	2964	640	1612	3774
COTV flt cost, $M/yr	1143	3648	9984	2831	6062	10071
Subtotal	1749	5159	13552	3518	7787	14124
HLLV flt cost, $M/yr	9725	25866	76870	4707	12595	36234
TOTAL TRANSPORTATION COST $M	11474	31025	90422	8225	20382	50358
Specific cost, $/Kg SPS	60.42	94.26	189.62	41.63	52.47	84.48

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)
YEAR 2007 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	5.260	5.260	5.260	5.260	5.260	5.260
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	236.700	410.280	594.380	246.252	484.172	742.964
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	5334	7616	9899	2472	3524	4587
POTV flts/yr	53	102	198	25	47	92
POTV prop wt, 10^3T/yr	8.64	16.45	32.07	4.00	7.61	14.86
POTV flt cost, \$M/yr	128	305	752	59	141	349
POTV fleet size, units	2	2	4	2	2	2
POTV replacement, units	0	0	4	0	0	2
HLLV flts/yr	21	42	91	10	20	43
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	6144	8774	11404	7816	11162	14518
PLV flts/yr	61	117	228	78	149	290
PLV flt cost, \$M/yr	627	1579	3695	797	2009	4704
PLV fleet size, units	2	4	8	2	4	10
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	3.51	4.57	5.94	1.16	1.66	2.16
Persnl consum, 10^3T/yr	4.48	9.14	15.44	2.08	4.23	7.15
COTV flts/yr	27	55	107	1	1	1
HLLV flts/yr	18	32	56	7	14	24
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.48	0.69	0.90	2.52	3.60	4.68
Persnl consum, 10^3T/yr	0.68	1.39	2.35	4.49	9.16	15.49
HLLV flts/yr	3	5	8	16	30	53

TABLE VI-F-2 (CONT'D)

YEAR 2007 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3 T/yr	236.700	410.280	594.380	246.252	484.172	742.964
COTV flts/yr	789	1641	2972	84	84	84
HLLV flts/yr	532	968	1556	553	1142	1945
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	247.711	429.729	626.956	250.989	492.908	757.833
Total COTV flts/yr	826	1719	3135	86	86	86
COTV prop wt, 10^3 T/yr	473.95	986.66	1799.36	66.82	139.83	291.27
COTV flt cost, $M/yr	1404	4469	12226	3517	7540	12533
COTV fleet size, units	11	28	60	86	86	86
COTV replacement, units	0	6	65	0	0	0
HLLV flts/yr	1131	2472	5010	242	520	1133
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	758.33	1491.91	2567.34	368.58	731.79	1221.67
Total HLLV flts/yr	1704	3519	6721	828	1726	3198
HLLV flt cost, $M/yr	11929	31668	94091	5798	15533	44773
HLLV fleet size, units	23	58	129	11	28	61
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	128	305	752	59	141	349
PLV flt cost, $M/yr	627	1579	3695	797	2009	4704
COTV flt cost, $M/yr	1404	4469	12226	3517	7540	12533
Subtotal	2158	6353	16673	4374	9690	17586
HLLV flt cost, $M/yr	11929	31668	94091	5798	15533	44773
TOTAL TRANSPORTATION COST $M	14087	38021	110764	10171	25223	62359
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2008 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	5.310	5.310	5.310	5.310	5.310	5.310
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	238.950	414.180	600.030	248.593	488.775	750.027
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	5384	7689	9993	2496	3558	4630
POTV flts/yr	54	103	200	25	47	93
POTV prop wt, 10^3T/yr	8.72	16.61	32.38	4.04	7.68	15.00
POTV flt cost, $M/yr	129	308	759	60	142	352
POTV fleet size, units	2	2	4	2	2	2
POTV replacement, units	0	0	4	0	0	2
HLLV flts/yr	21	42	92	10	20	44
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	6202	8857	11512	7891	11268	14656
PLV flts/yr	62	118	230	79	150	293
PLV flt cost, $M/yr	633	1594	3730	805	2028	4748
PLV fleet size, units	2	4	8	2	5	10
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	3.55	4.61	5.99	1.17	1.68	2.18
Persnl consum, 10^3T/yr	4.52	9.23	15.59	2.10	4.27	7.22
COTV flts/yr	27	55	108	1	1	1
HLLV flts/yr	18	33	57	7	14	25
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.49	0.70	0.91	2.54	3.63	4.72
Persnl consum, 10^3T/yr	0.68	1.40	2.37	4.53	9.25	15.64
HLLV flts/yr	3	5	9	16	30	53

TABLE VI-F-2 (CONT'D)

YEAR 2008 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	238.950	414.180	600.030	248.593	488.775	750.027
COTV flts/yr	797	1657	3000	85	85	85
HLLV flts/yr	537	977	1571	559	1153	1963
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	250.065	433.814	632.915	253.375	497.594	765.037
Total COTV flts/yr	834	1735	3165	87	86	87
COTV prop wt, 10^3T/yr	478.46	996.04	1816.47	67.46	141.16	294.04
COTV flt cost, \$M/yr	1417	4512	12342	3550	7611	12652
COTV fleet size, units	11	28	61	86	86	86
COTV replacement, units	0	6	66	0	0	0
HLLV flts/yr	1141	2495	5057	244	525	1143
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	765.54	1506.09	2591.75	372.08	738.75	1233.29
Total HLLV flts/yr	1720	3552	6785	836	1742	3229
HLLV flt cost, \$M/yr	12042	31969	94986	5853	15681	45199
HLLV fleet size, units	24	58	130	11	29	62
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, \$M/yr	129	308	759	60	142	352
PLV flt cost, \$M/yr	633	1594	3730	805	2028	4748
COTV flt cost, \$M/yr	1417	4512	12342	3550	7611	12652
Subtotal	2179	6413	16831	4415	9782	17753
HLLV flt cost, \$M/yr	12042	31969	94986	5853	15681	45199
TOTAL TRANSPORTATION COST \$M	14221	38382	111817	10268	25463	62952
Specific cost, \$/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2009 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	5.360	5.360	5.360	5.360	5.360	5.360
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	241.200	418.080	605.680	250.934	493.377	757.089
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	5435	7761	10088	2519	3591	4674
POTV flts/yr	54	103	202	25	48	93
POTV prop wt, 10^3T/yr	8.80	16.76	32.68	4.08	7.76	15.14
POTV flt cost, $M/yr	130	310	767	60	144	355
POTV fleet size, units	2	2	4	2	2	2
POTV replacement, units	0	0	4	0	0	2
HLLV flts/yr	21	43	93	10	20	44
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	6260	8940	11620	7965	11374	14794
PLV flts/yr	63	119	232	80	152	296
PLV flt cost, $M/yr	639	1609	3765	812	2047	4793
PLV fleet size, units	2	4	8	2	5	11
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	3.58	4.65	6.05	1.18	1.69	2.20
Persnl consum, 10^3T/yr	4.57	9.32	15.74	2.12	4.31	7.29
COTV flts/yr	27	56	109	1	1	1
HLLV flts/yr	18	33	57	7	14	25
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.49	0.71	0.92	2.57	3.67	4.77
Persnl consum, 10^3T/yr	0.69	1.42	2.39	4.57	9.34	15.79
HLLV flts/yr	[illegible]	5	9	16	31	54

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2009 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3 T/yr	241.200	418.080	605.680	250.934	493.377	757.089
COTV flts/yr	804	1672	3028	86	86	86
HLLV flts/yr	542	986	1586	564	1164	1982
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	252.420	437.899	638.875	255.760	502.279	772.240
Total COTV flts/yr	841	1752	3194	87	87	87
COTV prop wt, 10^3 T/yr	482.96	1005.42	1833.57	68.09	142.49	296.81
COTV flt cost, $M/yr	1430	4554	12458	3584	7683	12772
COTV fleet size, units	12	29	61	87	87	87
COTV replacement, units	0	6	67	0	0	0
HLLV flts/yr	1152	2519	5105	246	530	1154
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	772.75	1520.27	2616.15	375.58	745.70	1244.90
Total HLLV flts/yr	1737	3586	6849	844	1759	3259
HLLV flt cost, $M/yr	12156	32270	95880	5908	15829	45625
HLLV fleet size, units	24	59	131	12	29	62
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	130	310	767	60	144	355
PLV flt cost, $M/yr	639	1609	3765	812	2047	4793
COTV flt cost, $M/yr	1430	4554	12458	3584	7683	12772
Subtotal	2199	6474	16990	4457	9874	17920
HLLV flt cost, $M/yr	12156	32270	95880	5908	15829	45625
TOTAL TRANSPORTATION COST $M	14355	38744	112870	10365	25703	63545
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

Construction + Repair
Scenario C'

TABLE VI-F-2 (CONT'D)

YEAR 2010 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	5.410	5.410	5.410	5.410	5.410	5.410
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	243.450	421.980	611.330	253.275	497.980	764.152
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	5486	7834	10182	2543	3625	4718
POTV flts/yr	55	104	204	25	48	94
POTV prop wt, 10^3T/yr	8.89	16.92	32.99	4.12	7.83	15.28
POTV flt cost, $M/yr	132	313	774	61	145	359
POTV fleet size, units	2	2	4	2	2	2
POTV replacement, units	0	0	4	0	0	2
HLLV flts/yr	22	43	93	10	21	45
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	6319	9024	11729	8039	11480	14932
PLV flts/yr	63	120	235	80	153	299
PLV flt cost, $M/yr	645	1624	3800	820	2066	4838
PLV fleet size, units	2	4	8	2	5	11
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	3.61	4.70	6.11	1.20	1.71	2.22
Persnl consum, 10^3T/yr	4.61	9.40	15.88	2.14	4.35	7.36
COTV flts/yr	27	56	110	1	1	1
HLLV flts/yr	18	33	58	7	14	25
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.50	0.71	0.93	2.59	3.70	4.81
Persnl consum, 10^3T/yr	0.70	1.43	2.41	4.61	9.42	15.93
HLLV flts/yr	3	5	9	6	31	54

TABLE VI-F-2 (CONT'D)

YEAR 2010 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	243.450	421.980	611.330	253.275	497.980	764.152
COTV flts/yr	812	1688	3057	87	87	87
HLLV flts/yr	547	995	1600	569	1174	2000
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	254.775	441.984	644.835	258.146	506.964	779.444
Total COTV flts/yr	849	1768	3224	88	88	88
COTV prop wt, 10^3T/yr	487.47	1014.79	1850.68	68.73	143.81	299.58
COTV flt cost, $M/yr	1444	4597	12574	3617	7755	12891
COTV fleet size, units	12	29	62	88	88	88
COTV replacement, units	0	6	67	0	0	0
HLLV flts/yr	1163	2542	5152	249	535	1165
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	779.96	1534.45	2640.56	379.09	752.66	1256.51
Total HLLV flts/yr	1753	3619	6912	852	1775	3289
HLLV flt cost, $M/yr	12269	32571	96774	5963	15976	46050
HLLV fleet size, units	24	59	133	12	29	63
HLLV replacement, units	0	0	0	0	0	0
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	132	313	774	61	145	359
PLV flt cost, $M/yr	645	1624	3800	820	2066	4838
COTV flt cost, $M/yr	1444	4597	12574	3617	7755	12891
Subtotal	2220	6534	17148	4498	9966	18087
HLLV flt cost, $M/yr	12269	32571	96774	5963	15976	46050
TOTAL TRANSPORTATION COST $M	14489	39105	113923	10461	25942	64137
Specific cost, $/Kg SPS	59.51	92.67	186.35	41.30	52.10	83.93

TABLE VI-F-3

Maximum Fleet Size Comparison

Nominal Values

Construction + Repair

Year 2010

Vehicle	GEO Construction		LEO Construction	
	Scenario A'	Scenario C'	Scenario A'	Scenario C'
HLLV	24	59	12	29
PLV	2	4	2	5
COTV	12	29	36	88
POTV	2	2	2	2
Total SPS in place at end of year	22	46	22	46

Construction Only
Scenario A'

TABLE VI-F-4

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	22.000	22.000	22.000	22.000	22.000	22.000
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	990.000	1716.000	2486.000	1029.952	2025.056	3107.456
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	22308	31856	41404	10340	14740	19184
POTV flts/yr	223	425	828	103	197	384
POTV prop wt, 10^3T/yr	36.14	68.81	134.15	16.75	31.84	62.16
POTV flt cost, $M/yr	535	1274	3147	248	590	1458
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	6	31	0	2	13
HLLV flts/yr	88	175	380	42	83	181
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	25696	36696	47696	32692	46684	60720
PLV flts/yr	257	489	954	327	622	1214
PLV flt cost, $M/yr	2621	6605	15454	3335	8403	19673
PLV fleet size, units	2	2	2	2	2	3
PLV replacement, units	0	3	17	0	4	22
C. GEO BASE SUPPORT						
Base, 10^3T/yr	6.00	12.00	18.00	1.50	2.00	2.50
Equip & consum, 10^3T/yr	14.70	19.10	24.84	4.86	6.95	9.04
Persnl consum, 10^3T/yr	18.74	38.24	64.59	8.69	17.69	29.92
COTV flts/yr	131	277	537	5	5	5
HLLV flts/yr	89	164	281	34	63	109
D. LEO BASE SUPPORT						
Base, 10^3T/yr	1.50	2.00	2.50	6.00	12.00	18.00
Equip & consum, 10^3T/yr	2.02	2.90	3.76	10.54	15.05	19.56
Persnl consum, 10^3T/yr	2.84	5.81	9.81	18.77	38.32	64.79
HLLV flts/yr	14	25	42	79	154	268

Construction Only
Scenario A'

TABLE VI-F-4 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	990.000	1716.000	2486.000	1029.952	2025.056	3107.456
COTV flts/yr	3300	6864	12430	352	352	352
HLLV flts/yr	2225	4047	6508	2314	4776	8135
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	1042.052	1809.346	2640.248	1051.263	2063.593	3172.144
Total COTV flts/yr	3474	7237	13201	359	359	359
COTV prop wt, 10^3T/yr	1993.79	4154.26	7577.51	279.88	585.40	1219.20
COTV flt cost, $M/yr	5905	18817	51485	14731	31565	52462
COTV fleet size, units	3	7	16	22	22	22
COTV replacement, units	32	137	512	337	336	337
HLLV flts/yr	4757	10408	21096	1013	2177	4741
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	3191.42	6283.19	10813.38	1549.72	3075.62	5131.59
Total HLLV flts/yr	7172	14819	28307	3483	7254	13433
HLLV flt cost, $M/yr	50202	133370	396302	24378	65284	188069
HLLV fleet size, units	6	15	34	3	7	16
HLLV replacement, units	12	34	108	6	17	51
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	535	1274	3147	248	590	1458
PLV flt cost, $M/yr	2621	6605	15454	3335	8403	19673
COTV flt cost, $M/yr	5905	18817	51485	14731	31565	52462
Subtotal	9061	26697	70085	18313	40558	73593
HLLV flt cost, $M/yr	50202	133370	396302	24378	65284	188069
TOTAL TRANSPORTATION COST $M	59264	160066	466387	42691	105843	261662
Specific cost, $/Kg SPS	59.86	93.28	187.61	41.45	52.27	84.20
Specific cost, $/KWe buss	269.[illegible]8	727.57	2119.94	194.05	481.10	1189.37

Construction Only
Scenario C'

TABLE VI-F-5

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	46.000	46.000	46.000	46.000	46.000	46.000
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	2070.000	3588.000	5198.000	2153.536	4234.208	6497.408
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	46644	66608	86572	21620	30820	40112
POTV flts/yr	466	888	1731	216	411	802
POTV prop wt, 10^3T/yr	75.56	143.87	280.49	35.02	66.57	129.96
POTV flt cost, $M/yr	1119	2664	6579	519	1233	3049
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	3	16	67	0	6	30
HLLV flts/yr	183	366	794	87	175	379
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	53728	76728	99728	68356	97612	126960
PLV flts/yr	537	1023	1995	684	1301	2539
PLV flt cost, $M/yr	5480	13811	32312	6972	17570	41135
PLV fleet size, units	2	2	4	2	2	6
PLV replacement, units	2	8	35	3	11	45
C. GEO BASE SUPPORT						
Base, 10^3T/yr	15.00	30.00	45.00	3.75	5.00	6.25
Equip & consum, 10^3T/yr	30.73	39.93	51.93	10.17	14.54	18.91
Persnl consum, 10^3T/yr	[illegible]9.19	79.95	135.06	18.17	36.98	62.56
COTV flts/yr	[illegible]83	600	1160	11	10	10
HLLV flts/yr	191	353	607	72	133	230
D. LEO BASE SUPPORT						
Base, 10^3T/yr	3.75	5.00	6.25	15.00	30.00	45.00
Equip & consum, 10^3T/yr	4.23	6.07	7.87	22.03	31.46	40.89
Persnl consum, 10^3T/yr	5.9[illegible]	12.14	20.52	39.24	80.13	135.47
HLLV flts/yr	31	55	91	171	334	579

Construction Only
Scenario C'

TABLE VI-F-5 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	2070.000	3588.000	5198.000	2153.536	4234.208	6497.408
COTV flts/yr	6900	14352	25990	736	736	736
HLLV flts/yr	4652	8462	13607	4839	9986	17009
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	2181.292	3788.088	5527.882	.2198.709	4315.603	6633.687
Total COTV flts/yr	7271	15152	27639	751	750	751
COTV prop wt, 10^3T/yr	4173.54	8697.45	15865.02	585.37	1224.24	2549.63
COTV flt cost, $M/yr	12361	39396	107794	30809	66013	109710
COTV fleet size, units	6	16	33	47	47	47
COTV replacement, units	66	287	1072	704	703	704
HLLV flts/yr	9957	21790	44169	2119	4553	9914
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	6681.03	13155.27	22640.66	3243.66	6436.93	10738.66
Total HLLV flts/yr	15014	31027	59269	7289	15181	28112
HLLV flt cost, $M/yr	105095	279239	829763	51024	136633	393564
HLLV fleet size, units	13	32	71	6	16	34
HLLV replacement, units	25	72	225	12	35	107
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	1119	2664	6579	519	1233	3049
PLV flt cost, $M/yr	5480	13811	32312	6972	17570	41135
COTV flt cost, $M/yr	12361	39396	107794	30809	66013	109710
Subtotal	18960	55871	146685	38300	84816	153893
HLLV flt cost, $M/yr	105095	279239	829763	51024	136633	393564
TOTAL TRANSPORTATION COST $M	124055	335111	976448	89324	221449	547457
Specific cost, $/Kg SPS	59.93	93.40	187.85	41.48	52.30	84.26
Specific cost, $/KWe buss	269.69	728.50	2122.71	194.18	481.41	1190.12

TABLE VI-F-6

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	1.178	1.178	1.178	1.178	1.178	1.178
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	52.988	91.845	133.058	55.126	108.387	166.320
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	1194	1705	2216	553	789	1027
POTV flts/yr	12	23	44	6	11	21
POTV prop wt, 10^3T/yr	1.93	3.68	7.18	0.90	1.70	3.33
POTV flt cost, $M/yr	29	68	168	13	32	78
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	0	0	0	0
HLLV flts/yr	5	9	20	2	4	10
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	1375	1964	2553	1750	2499	3250
PLV flts/yr	14	26	51	17	33	65
PLV flt cost, $M/yr	140	354	827	178	450	1053
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	0
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.79	1.02	1.33	0.26	0.37	0.48
Persnl consum, 10^3T/yr	1.00	2.05	3.46	0.47	0.95	1.60
COTV flts/yr	6	12	24	0	0	0
HLLV flts/yr	4	7	13	2	3	5
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.11	0.16	0.20	0.56	0.81	1.05
Persnl consum, 10^3T/yr	0.15	0.31	0.53	1.00	2.05	3.47
HLLV flts/yr	1	1	2	4	7	12

Repair Only
Scenario A'

TABLE VI-F-6 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	52.988	91.845	133.058	55.126	108.387	166.320
COTV flts/yr	177	367	665	19	19	19
HLLV flts/yr	119	217	348	124	256	435
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	55.452	96.199	140.350	56.186	110.342	169.648
Total COTV flts/yr	185	385	702	19	19	19
COTV prop wt, 10^3T/yr	106.10	220.87	402.80	14.96	31.30	65.20
COTV flt cost, $M/yr	314	1000	2737	787	1688	2806
COTV fleet size, units	2	2	2	2	2	2
COTV replacement, units	0	6	26	17	17	17
HLLV flts/yr	253	553	1121	54	116	254
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	169.76	333.98	574.72	82.51	163.82	273.48
Total HLLV flts/yr	381	788	1505	185	386	716
HLLV flt cost, $M/yr	2670	7089	21063	1298	3477	10023
HLLV fleet size, units	2	2	2	2	2	2
HLLV replacement, units	0	1	6	0	0	2
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	29	68	168	13	32	78
PLV flt cost, $M/yr	140	354	827	178	450	1053
COTV flt cost, $M/yr	314	1000	2737	787	1688	2806
Subtotal	483	1422	3732	979	2169	3937
HLLV flt cost, $M/yr	2670	7089	21063	1298	3477	10023
TOTAL TRANSPORTATION COST $M	3154	8511	24796	2277	5646	13960

TABLE VI-F-7

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	2.350	2.350	2.350	2.350	2.350	2.350
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	105.750	183.300	265.550	110.018	216.313	331.933
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	2383	3403	4423	1105	1575	2049
POTV flts/yr	24	45	88	11	21	41
POTV prop wt, 10^3T/yr	3.86	7.35	14.33	1.79	3.40	6.64
POTV flt cost, $M/yr	57	136	336	27	63	156
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	0	2	0	0	0
HLLV flts/yr	9	19	41	4	9	19
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	2745	3920	5095	3492	4987	6486
PLV flts/yr	27	52	102	35	66	130
PLV flt cost, $M/yr	280	706	1651	356	898	2101
PLV fleet size, units	2	2	2	2	2	2
PLV replacement, units	0	0	0	0	0	1
C. GEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	1.57	2.04	2.65	0.52	0.74	0.97
Persnl consum, 10^3T/yr	2.00	4.08	6.90	0.93	1.89	3.20
COTV flts/yr	12	24	48	0	0	0
HLLV flts/yr	8	14	25	3	6	11
D. LEO BASE SUPPORT						
Base, 10^3T/yr	0.00	0.00	0.00	0.00	0.00	0.00
Equip & consum, 10^3T/yr	0.22	0.31	0.40	1.13	1.61	2.09
Persnl consum, 10^3T/yr	0.30	0.62	1.05	2.00	4.09	6.92
HLLV flts/yr	1	2	4	7	13	24

TABLE VI-F-7 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3 T/yr	105.750	183.300	265.550	110.018	216.313	331.933
COTV flts/yr	353	733	1328	38	38	38
HLLV flts/yr	238	432	695	247	510	869
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3 T/yr	110.669	191.989	280.104	112.134	220.216	338.576
Total COTV flts/yr	369	768	1401	38	38	38
COTV prop wt, 10^3 T/yr	211.75	440.81	803.90	29.85	62.47	130.13
COTV flt cost, $M/yr	627	1997	5462	1571	3368	5599
COTV fleet size, units	2	2	2	3	3	3
COTV replacement, units	2	13	54	36	36	36
HLLV flts/yr	505	1104	2238	108	232	506
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3 T/yr	338.80	666.54	1147.01	164.67	326.94	545.81
Total HLLV flts/yr	761	1572	3003	370	771	1429
HLLV flt cost, $M/yr	5329	14148	42037	2590	6940	20003
HLLV fleet size, units	2	2	4	2	2	2
HLLV replacement, units	0	3	11	0	1	5
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	57	136	336	27	63	156
PLV flt cost, $M/yr	280	706	1651	356	898	2101
COTV flt cost, $M/yr	627	1997	5462	1571	3368	5599
Subtotal	964	2838	7449	1954	4329	7857
HLLV flt cost, $M/yr	5329	14148	42037	2590	6940	20003
TOTAL TRANSPORTATION COST $M	6294	16987	49486	4544	11269	27860

Construction + Repair
Scenario A'

TABLE VI-F-8
YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	23.2	23.2	23.2	23.2	23.2	23.2
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
GEO persnl/SPS	507	724	941	235	335	436
GEO persnl consum/SPS, 10^3T	0.852	1.738	2.936	0.395	0.804	1.360
GEO Base, 10^3T	6.000	12.000	18.000	1.500	2.000	2.500
GEO Base equip&consum/SPS, 10^3T	0.668	0.868	1.129	0.221	0.316	0.411
LEO persnl/SPS	77	110	143	508	726	944
LEO persnl consum/SPS, 10^3T	0.129	0.264	0.446	0.853	1.742	2.945
LEO Base, 10^3T	1.500	2.000	2.500	6.000	12.000	18.000
LEO Base equip&consum/SPS, 10^3T	0.092	0.132	0.171	0.479	0.684	0.889
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	2.926	5.753	8.828
Total inert wt, 10^3T	0.036	0.036	0.036	0.422	0.829	1.413
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	0.779	1.632	3.393
Flt cost, $M/flt	1.7	2.6	3.9	41.0	88.0	146.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, $M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

Construction + Repair
Scenario A'

TABLE VI-F-8 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	23.178	23.178	23.178	23.178	23.178	23.178
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	1042.988	1807.845	2619.058	1085.078	2133.443	3273.776
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	23502	33561	43620	10893	15529	20211
POTV flts/yr	235	447	872	109	207	404
POTV prop wt, 10^3T/yr	38.07	72.49	141.33	17.65	33.54	65.48
POTV flt cost, \$M/yr	564	1342	3315	261	621	1536
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	0	7	33	0	2	14
HLLV flts/yr	92	185	400	44	88	191
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	27071	38660	50249	34442	49183	63970
PLV flts/yr	271	515	1005	344	656	1279
PLV flt cost, \$M/yr	2761	6959	16281	3513	8853	20726
PLV fleet size, units	2	2	2	2	2	3
PLV replacement, units	0	3	18	0	5	23
C. GEO BASE SUPPORT						
Base, 10^3T/yr	6.00	12.00	18.00	1.50	2.00	2.50
Equip & consum, 10^3T/yr	15.48	20.12	26.17	5.12	7.32	9.53
Persnl consum, 10^3T/yr	19.75	40.28	68.05	9.16	18.63	31.52
COTV flts/yr	137	290	561	5	5	5
HLLV flts/yr	93	171	294	35	66	114
D. LEO BASE SUPPORT						
Base, 10^3T/yr	1.50	2.00	2.50	6.00	12.00	18.00
Equip & consum, 10^3T/yr	2.13	3.06	3.96	11.10	15.85	20.60
Persnl consum, 10^3T/yr	2.99	6.12	10.34	19.77	40.38	68.26
HLLV flts/yr	15	26	44	83	161	280

Construction + Repair
Scenario A'

TABLE VI-F-8 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	1042.988	1807.845	2619.058	1085.078	2133.443	3273.776
COTV flts/yr	3477	7231	13095	371	371	371
HLLV flts/yr	2344	4264	6856	2438	5032	8570
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	1097.505	1905.545	2780.598	1107.449	2173.935	3341.792
Total COTV flts/yr	3658	7622	13903	378	378	379
COTV prop wt, 10^3T/yr	2099.89	4375.13	7980.32	294.84	616.70	1284.40
COTV flt cost, $M/yr	6219	19818	54222	15518	33253	55268
COTV fleet size, units	3	8	17	24	24	24
COTV replacement, units	33	145	539	355	354	355
HLLV flts/yr	5010	10961	22218	1067	2294	4995
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	3[illegible]61.18	6617.16	11388.11	1632.23	3239.44	5405.08
Total HLLV flts/yr	7553	15607	29812	3668	7640	14149
HLLV flt cost, $M/yr	52873	140459	417365	25676	68762	198092
HLLV fleet size, units	6	16	36	3	8	17
HLLV replacement, units	12	36	113	6	18	54
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	564	1342	3315	261	621	1536
PLV flt cost, $M/yr	2761	6959	16281	3513	8853	20726
COTV flt cost, $M/yr	6219	19818	54222	15518	33253	55268
Subtotal	9545	28119	73817	19292	42727	77530
HLLV flt cost, $M/yr	52873	140459	417365	25676	68762	198092
TOTAL TRANSPORTATION COST $M	62417	168578	491183	44968	111489	275622
Specific cost, $/Kg SPS	59.84	93.25	187.54	41.44	52.26	84.19
Specific cost, $/KWe buss	283.71	766.26	2232.65	204.40	506.77	1252.83

TABLE VI-F-9
YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	48.4	48.4	48.4	48.4	48.4	48.4
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
GEO persnl/SPS	507	724	941	235	335	436
GEO persnl consum/SPS, 10^3T	0.852	1.738	2.936	0.395	0.804	1.360
GEO Base, 10^3T	15.000	30.000	45.000	3.750	5.000	6.250
GEO Base equip&consum/SPS, 10^3T	0.668	0.868	1.129	0.221	0.316	0.411
LEO persnl/SPS	77	110	143	508	726	944
LEO persnl consum/SPS, 10^3T	0.129	0.264	0.446	0.853	1.742	2.945
LEO Base, 10^3T	3.750	5.000	6.250	15.000	30.000	45.000
LEO Base equip&consum/SPS, 10^3T	0.092	0.132	0.171	0.479	0.684	0.889
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	2.926	5.753	8.828
Total inert wt, 10^3T	0.036	0.036	0.036	0.422	0.829	1.413
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	0.779	1.632	3.393
Flt cost, $M/flt	1.7	2.6	3.9	41.0	88.0	146.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, $M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

Construction + Repair
Scenario C'

TABLE VI-F-9 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	48.350	48.350	48.350	48.350	48.350	48.350
SPS mass each, 10^3T	45.000	78.000	113.000	46.816	92.048	141.248
Total SPS mass, 10^3T	2175.750	3771.300	5463.550	2263.554	4450.521	6829.341
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	49027	70011	90995	22725	32395	42161
POTV flts/yr	490	933	1820	227	432	843
POTV prop wt, 10^3T/yr	79.42	151.22	294.82	36.81	69.97	136.60
POTV flt cost, $M/yr	1177	2800	6916	545	1296	3204
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	3	17	71	0	7	32
HLLV flts/yr	192	385	835	92	183	399
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	56473	80648	104823	71848	102599	133446
PLV flts/yr	565	1075	2096	718	1368	2669
PLV flt cost, $M/yr	5760	14517	33963	7329	18468	43237
PLV fleet size, units	2	2	5	2	3	6
PLV replacement, units	2	9	37	3	11	47
C. GEO BASE SUPPORT						
Base, 10^3T/yr	15.00	30.00	45.00	3.75	5.00	6.25
Equip & consum, 10^3T/yr	32.30	41.97	54.59	10.69	15.28	19.87
Persnl consum, 10^3T/yr	41.19	84.03	141.96	19.10	38.87	65.76
COTV flts/yr	295	624	1208	11	10	10
HLLV flts/yr	199	368	632	75	140	241
D. LEO BASE SUPPORT						
Base, 10^3T/yr	3.75	5.00	6.25	15.00	30.00	45.00
Equip & consum, 10^3T/yr	4.45	6.38	8.27	23.16	33.07	42.98
Persnl consum, 10^3T/yr	6.24	12.76	21.56	41.24	84.23	142.39
HLLV flts/yr	32	57	94	178	347	603

Construction + Repair
Scenario C'

TABLE VI-F-9 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	2175.750	3771.300	5463.550	2263.554	4450.521	6829.341
COTV flts/yr	7253	15085	27318	774	774	774
HLLV flts/yr	4889	8895	14302	5087	10497	17878
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	2291.961	3980.077	5807.986	2310.843	4535.819	6972.262
Total COTV flts/yr	7640	15920	29040	790	788	790
COTV prop wt, 10^3T/yr	4385.29	9138.26	16668.92	615.22	1286.71	2679.76
COTV flt cost, $M/yr	12988	41393	113256	32380	69382	115309
COTV fleet size, units	7	16	35	49	49	49
COTV replacement, units	70	302	1127	740	739	740
HLLV flts/yr	10462	22894	46407	2227	4786	10421
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	7019.83	13821.81	23787.67	3408.33	6763.88	11284.47
Total HLLV flts/yr	15775	32599	62271	7659	15953	29540
HLLV flt cost, $M/yr	110424	293387	871799	53614	143573	413567
HLLV fleet size, units	13	33	75	7	16	35
HLLV replacement, units	26	75	237	13	37	112
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	1177	2800	6916	545	1296	3204
PLV flt cost, $M/yr	5760	14517	33963	7329	18468	43237
COTV flt cost, $M/yr	12988	41393	113256	32380	69382	115309
Subtotal	19925	58710	154134	40254	89145	161750
HLLV flt cost, $M/yr	110424	293387	871799	53614	143573	413567
TOTAL TRANSPORTATION COST $M	130349	352097	1025933	93868	232718	575317
Specific cost, $/Kg SPS	59.91	93.36	187.78	41.47	52.29	84.24
Specific cost, $/KWe buss	283.57	765.43	2230.29	204.06	505.91	1250.69

TABLE VI-F-10

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS				48.4	48.4	48.4
SPS mass each, 10^3T				81.120	92.048	97.504
GEO persnl/SPS				335	335	335
GEO persnl consum/SPS, 10^3T				0.804	0.804	0.804
GEO Base, 10^3T				5.000	5.000	5.000
GEO Base equip&consum/SPS, 10^3T				0.316	0.316	0.316
LEO persnl/SPS				726	726	726
LEO persnl consum/SPS, 10^3T				1.742	1.742	1.742
LEO Base, 10^3T				30.000	30.000	30.000
LEO Base equip&consum/SPS, 10^3T				0.684	0.684	0.684
LEO prop storage/transfer factor				1.069		
GEO prop storage/transfer factor				1.190		
A. POTV CHARACTERISTICS						
Passengers/flt				75	75	75
Inert wt, 10^3T				0.021	0.021	0.021
Propellant/flt, 10^3T				0.108	0.108	0.108
Prop dwn/flt, 10^3T				0.054	0.054	0.054
Flt cost, \$M/flt				3.0	3.0	3.0
Flt turnaround, days				6	6	6
Mission life				50	50	50
B. PLV CHARACTERISTICS						
Passengers/flt				75	75	75
Flt cost, \$M/flt				13.5	13.5	13.5
Flt turnaround, days				11	11	11
Mission life				100	100	100
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T				5.070	5.753	6.094
Total inert wt, 10^3T				0.731	0.829	0.975
Expended inert wt, 10^3T				0.000	0.000	0.000
Propellant/flt, 10^3T				1.384	1.632	2.398
Flt cost, \$M/flt				72.0	88.0	101.0
Flt turnaround, days				365	365	365
Mission life				1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T				0.424	0.424	0.424
Flt cost, \$M/flt				9.0	9.0	9.0
Flt turnaround, days				6	6	6
Mission life				300	300	300

Construction + Repair
Scenario C'

TABLE VI-F-10(CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS				48.350	48.350	48.350
SPS mass each, 10^3T				81.120	92.048	97.504
Total SPS mass, 10^3T				3922.152	4450.521	4714.318
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr				32395	32395	32395
POTV flts/yr				432	432	432
POTV prop wt, 10^3T/yr				69.97	69.97	69.97
POTV flt cost, $M/yr				1296	1296	1296
POTV fleet size, units				2	2	2
POTV replacement, units				7	7	7
HLLV flts/yr				185	185	185
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr				102599	102599	102599
PLV flts/yr				1368	1368	1368
PLV flt cost, $M/yr				18468	18468	18468
PLV fleet size, units				3	3	3
PLV replacement, units				11	11	11
C. GEO BASE SUPPORT						
Base, 10^3T/yr				5.00	5.00	5.00
Equip & consum, 10^3T/yr				15.28	15.28	15.28
Persnl consum, 10^3T/yr				38.87	38.87	38.87
COTV flts/yr				12	10	10
HLLV flts/yr				140	140	140
D. LEO BASE SUPPORT						
Base, 10^3T/yr				30.00	30.00	30.00
Equip & consum, 10^3T/yr				33.07	33.07	33.07
Persnl consum, 10^3T/yr				84.23	84.23	84.23
HLLV flts/yr				347	347	347

Construction + Repair
Scenario C'

TABLE VI-F-10 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr				3922.152	4450.521	4714.318
COTV flts/yr				774	774	774
HLLV flts/yr				9250	10497	11119
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr				4007.217	4535.586	4799.383
Total COTV flts/yr				790	788	788
COTV prop wt, 10^3T/yr				1093.88	1286.65	1888.57
COTV flt cost, $M/yr				56907	69378	79543
COTV fleet size, units				49	49	49
COTV replacement, units				741	739	738
HLLV flts/yr				4146	4816	6617
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr				5964.94	6777.10	7804.67
Total HLLV flts/yr				14068	15984	18407
HLLV flt cost, $M/yr				126614	143854	165665
HLLV fleet size, units				14	16	19
HLLV replacement, units				32	37	42
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr				1296	1296	1296
PLV flt cost, $M/yr				18468	18468	18468
COTV flt cost, $M/yr				56907	69378	79543
Subtotal				76671	89142	99307
HLLV flt cost, $M/yr				126614	143854	165665
TOTAL TRANSPORTATION COST $M				203285	232995	264972
Specific cost, $/Kg SPS				51.83	52.35	56.21
Specific cost, $/KWe buss				441.92	506.51	576.03

TABLE VI-F-11

Effect of $COTV_L$ Performance Variance

Average Year Construction + Repair

16 Year Model - Scenario C'

$COTV_L$	Isp, sec	η, % Eff.	Array Oversize % SPS Mass	EPDS Scar % SPS Mass	COTV Inert % SPS Mass	COTV Cost/Flt $M	$ kg SPS*	$/KWe Buss*
"Min"	5000	70%	0%	4%	15%	77	51.83	441.92
"Nom"	5000	65%	13%	5%	17%	88	52.35	506.51
"Max"	5000	55%	18%	7%	20%	101	56.21	576.03

*For nominal estimates of SPS mass, personnel, consumables, POTV, PLV, HLLV.

TABLE VI-F-12
YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	48.4	48.4	48.4	48.4	48.4	48.4
SPS mass each, 10^3T	78.000	78.000	78.000	92.048	92.048	92.048
GEO persnl/SPS	724	724	724	335	335	335
GEO persnl consum/SPS, 10^3T	1.738	1.738	1.738	0.804	0.804	0.804
GEO Base, 10^3T	30.000	30.000	30.000	5.000	5.000	5.000
GEO Base equip&consum/SPS, 10^3T	0.868	0.868	0.868	0.316	0.316	0.316
LEO persnl/SPS	110	110	110	726	726	726
LEO persnl consum/SPS, 10^3T	0.264	0.264	0.264	1.742	1.742	1.742
LEO Base, 10^3T	5.000	5.000	5.000	30.000	30.000	30.000
LEO Base equip&consum/SPS, 10^3T	0.132	0.132	0.132	0.684	0.684	0.684
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	75	75	75	75	75	75
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	3.0	3.0	3.0	3.0	3.0	3.0
Flt turnaround, days	6	6	6	6	6	6
Mission life	50	50	50	50	50	50
B. PLV CHARACTERISTICS						
Passengers/flt	75	75	75	75	75	75
Flt cost, $M/flt	13.5	13.5	13.5	13.5	13.5	13.5
Flt turnaround, days	11	11	11	11	11	11
Mission life	100	100	100	100	100	100
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.250	0.250	0.250	5.753	5.753	5.753
Total inert wt, 10^3T	0.036	0.036	0.036	0.829	0.829	0.829
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	1.632	1.632	1.632
Flt cost, $M/flt	2.6	2.6	2.6	88.0	88.0	88.0
Flt turnaround, days	6	6	6	365	365	365
Mission life	50	50	50	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.424	0.424	0.424	0.424	0.424	0.424
Flt cost, $M/flt	4.0	to	20.0	4.0	to	20.0
Flt turnaround, days	6	6	6	6	6	6
Mission life	300	300	300	300	300	300

Construction + Repair
Scenario C'

TABLE VI-F-12 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY			LEO ASSY		
	MIN	NOM	MAX	MIN	NOM	MAX
No. of SPS	48.350	48.350	48.350	48.350	48.350	48.350
SPS mass each, 10^3T	78.000	78.000	78.000	92.048	92.048	92.048
Total SPS mass, 10^3T	3771.300	3771.300	3771.300	4450.521	4450.521	4450.521
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	70011	70011	70011	32395	32395	32395
POTV flts/yr	933	933	933	432	432	432
POTV prop wt, 10^3T/yr	151.60	151.60	151.60	70.14	70.14	70.14
POTV flt cost, $M/yr	2800	2800	2800	1296	1296	1296
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	17	17	17	7	7	7
HLLV flts/yr	386	386	386	185	185	185
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	80648	80648	80648	102599	102599	102599
PLV flts/yr	1075	1075	1075	1368	1368	1368
PLV flt cost, $M/yr	14517	14517	14517	18468	18468	18468
PLV fleet size, units	2	2	2	3	3	3
PLV replacement, units	9	9	9	11	11	11
C. GEO BASE SUPPORT						
Base, 10^3T/yr	30.00	30.00	30.00	5.00	5.00	5.00
Equip & consum, 10^3T/yr	41.97	41.97	41.97	15.28	15.28	15.28
Persnl consum, 10^3T/yr	84.03	84.03	84.03	38.87	38.87	38.87
COTV flts/yr	624	624	624	10	10	10
HLLV flts/yr	368	368	368	140	140	140
D. LEO BASE SUPPORT						
Base, 10^3T/yr	5.00	5.00	5.00	30.00	30.00	30.00
Equip & consum, 10^3T/yr	6.38	6.38	6.38	33.07	33.07	33.07
Persnl consum, 10^3T/yr	12.76	12.76	12.76	84.23	84.23	84.23
HLLV flts/yr	57	57	57	347	347	347

TABLE VI-F-12 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	3771.300	3771.300	3771.300	4450.521	4450.521	4450.521
COTV flts/yr	15085	15085	15085	774	774	774
HLLV flts/yr	8895	8895	8895	10497	10497	10497
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	3980.468	3980.468	3980.468	4535.778	4535.778	4535.778
Total COTV flts/yr	15922	15922	15922	788	788	788
COTV prop wt, 10^3T/yr	9139.15	9139.15	9139.15	1286.70	1286.70	1286.70
COTV flt cost, $M/yr	41397	41397	41397	69381	69381	69381
COTV fleet size, units	16	16	16	49	49	49
COTV replacement, units	302	302	302	739	739	739
HLLV flts/yr	22896	22896	22896	4816	4816	4816
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	13823.18	13823.18	13823.18	6777.40	6777.40	6777.40
Total HLLV flts/yr	32602	32602	32602	15984	15984	15984
HLLV flt cost, $M/yr (4, 6, 8)	130407	195611	260815	63938	95907	127875
HLLV fleet size, units	33	33	33	16	16	16
HLLV replacement, units	75	75	75	37	37	37
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	2800	2800	2800	1296	1296	1296
PLV flt cost, $M/yr	14517	14517	14517	18468	18468	18468
COTV flt cost, $M/yr	41397	41397	41397	69381	69381	69381
Subtotal	58714	58714	58714	89144	89144	89144
HLLV flt cost, $M/yr	130407	195611	260815	63938	95907	127875
TOTAL TRANSPORTATION COST $M	189121	254325	319529	153082	185051	217020
Specific cost, $/Kg SPS	50.15	67.44	84.73	34.40	41.58	48.76
Specific cost, $/KWe buss	411.13	552.88	694.04	332.79	402.28	471.78

Construction + Repair
Scenario C'

TABLE VI-F-12 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO_3						
Total SPS mass, 10^3T/yr	3771.300	3771.300	3771.300	4450.521	4450.521	4450.521
COTV flts/yr	15085	15085	15085	774	774	774
HLLV flts/yr	8895	8895	8895	10497	10497	10497
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	3980.468	3980.468	3980.468	4535.778	4535.778	4535.778
Total COTV flts/yr	15922	15922	15922	788	788	788
COTV prop wt, 10^3T/yr	9139.15	9139.15	9139.15	1286.70	1286.70	1286.70
COTV flt cost, $M/yr	41397	41397	41397	69381	69381	69381
COTV fleet size, units	16	16	16	49	49	49
COTV replacement, units	302	302	302	739	739	739
HLLV flts/yr	22896	22896	22896	4816	4816	4816
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	13823.18	13823.18	13823.18	6777.40	6777.40	6777.40
Total HLLV flts/yr	32602	32602	32602	15984	15984	15984
HLLV flt cost, $M/yr (10, 12, 14)	326018	391222	456426	159844	191813	223782
HLLV fleet size, units	33	33	33	16	16	16
HLLV replacement, units	75	75	75	37	37	37
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	2800	2800	2800	1296	1296	1296
PLV flt cost, $M/yr	14517	14517	14517	18468	18468	18468
COTV flt cost, $M/yr	41397	41397	41397	69381	69381	69381
Subtotal	58714	58714	58714	89144	89144	89144
HLLV flt cost, $M/yr	326018	391222	456426	159844	191813	223782
TOTAL TRANSPORTATION COST $M	384732	449936	515140	248989	280958	312926
Specific cost, $/Kg SPS	102.02	119.31	136.59	55.95	63.13	70.31
Specific cost, $/KWe buss	836.57	978.12	1119.87	541.28	610.78	680.27

TABLE VI-F-12 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	3771.300	3771.300	3771.300	4450.521	4450.521	4450.521
COTV flts/yr	15085	15085	15085	774	774	774
HLLV flts/yr	8895	8895	8895	10497	10497	10497
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	3980.468	3980.468	3980.468	4535.778	4535.778	4535.778
Total COTV flts/yr	15922	15922	15922	788	788	788
COTV prop wt, 10^3T/yr	9139.15	9139.15	9139.15	1286.70	1286.70	1286.70
COTV flt cost, $M/yr	41397	41397	41397	69381	69381	69381
COTV fleet size, units	16	16	16	49	49	49
COTV replacement, units	302	302	302	739	739	739
HLLV flts/yr	22896	22896	22896	4816	4816	4816
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	13823.18	13823.18	13823.18	6777.40	6777.40	6777.40
Total HLLV flts/yr	32602	32602	32602	15984	15984	15984
HLLV flt cost, $M/yr (16, 18, 20)	521629	586833	652037	255751	287720	319688
HLLV fleet size, units	33	33	33	16	16	16
HLLV replacement, units	75	75	75	37	37	37
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	2800	2800	2800	1296	1296	1296
PLV flt cost, $M/yr	14517	14517	14517	18468	18468	18468
COTV flt cost, $M/yr	41397	41397	41397	69381	69381	69381
Subtotal	58714	58714	58714	89144	89144	89144
HLLV flt cost, $M/yr	521629	586833	652037	255751	287720	319688
TOTAL TRANSPORTATION COST $M	580343	645547	710751	344895	376864	408833
Specific cost, $/Kg SPS	153.88	171.17	188.46	77.50	84.68	91.86
Specific cost, $/KWe buss	1261.62	1403.37	1545.11	749.77	819.27	888.77

Construction + Repair
Scenario C'

TABLE VI-F-13
16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

6/21/77

YEAR	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	48.4	48.4	48.4	48.4	48.4	48.4
SPS mass each, 10^3T	78.000	78.000	78.000	81.120	92.048	97.504
GEO persnl/SPS	724	724	724	335	335	335
GEO persnl consum/SPS, 10^3T	1.738	1.738	1.738	0.804	0.804	0.804
GEO Base, 10^3T	30.000	30.000	30.000	5.000	5.000	5.000
GEO Base equip&consum/SPS, 10^3T	0.868	0.868	0.868	0.316	0.316	0.316
LEO persnl/SPS	110	110	110	726	726	726
LEO persnl consum/SPS, 10^3T	0.264	0.264	0.264	1.742	1.742	1.742
LEO Base, 10^3T	5.000	5.000	5.000	30.000	30.000	30.000
LEO Base equip&consum/SPS, 10^3T	0.132	0.132	0.132	0.684	0.684	0.684
LEO prop storage/transfer factor	1.061			1.069		
GEO prop storage/transfer factor	1.108			1.190		
A. POTV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Inert wt, 10^3T	0.021	0.021	0.021	0.021	0.021	0.021
Propellant/flt, 10^3T	0.108	0.108	0.108	0.108	0.108	0.108
Prop dwn/flt, 10^3T	0.054	0.054	0.054	0.054	0.054	0.054
Flt cost, $M/flt	2.4	3.0	3.8	2.4	3.0	3.8
Flt turnaround, days	5	6	7	5	6	7
Mission life	100	50	25	100	50	25
B. PLV CHARACTERISTICS						
Passengers/flt	100	75	50	100	75	50
Flt cost, $M/flt	10.2	13.5	16.2	10.2	13.5	16.2
Flt turnaround, days	9	11	13	9	11	13
Mission life	150	100	50	150	100	50
C. COTV CHARACTERISTICS						
Payload/flt, 10^3T	0.300	0.250	0.200	5.070	5.753	6.094
Total inert wt, 10^3T	0.036	0.036	0.036	0.731	0.829	0.975
Expended inert wt, 10^3T	0.000	0.000	0.000	0.000	0.000	0.000
Propellant/flt, 10^3T	0.574	0.574	0.574	1.384	1.632	2.398
Flt cost, $M/flt	1.7	2.6	3.9	72.0	88.0	101.0
Flt turnaround, days	5	6	7	365	365	365
Mission life	100	50	25	1	1	1
D. HLLV CHARACTERISTICS						
Payload/flt, 10^3T	0.445	0.424	0.382	0.445	0.424	0.382
Flt cost, $M/flt	7.0	9.0	14.0	7.0	9.0	14.0
Flt turnaround, days	5	6	7	5	6	7
Mission life	400	300	200	400	300	200

Construction + Repair
Scenario C'

TABLE VI-F-13 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
No. of SPS	48.350	48.350	48.350	48.350	48.350	48.350
SPS mass each, 10^3T	78.000	78.000	78.000	81.120	92.048	97.504
Total SPS mass, 10^3T	3771.300	3771.300	3771.300	3922.152	4450.521	4714.318
A. MANNED TRANSFER TO GEO						
GEO man-trips/yr	70011	70011	70011	32395	32395	32395
POTV flts/yr	700	933	1400	324	432	648
POTV prop wt, 10^3T/yr	113.42	151.22	226.83	52.48	69.97	104.96
POTV flt cost, $M/yr	1680	2800	5321	777	1296	2462
POTV fleet size, units	2	2	2	2	2	2
POTV replacement, units	5	17	54	1	7	24
HLLV flts/yr	275	385	642	131	183	306
B. MANNED LAUNCH TO LEO						
LEO man-trips/yr	80648	80648	80648	102599	102599	102599
PLV flts/yr	806	1075	1613	1026	1368	2052
PLV flt cost, $M/yr	8226	14517	26130	10465	18468	33242
PLV fleet size, units	2	2	4	2	3	5
PLV replacement, units	3	9	29	5	11	36
C. GEO BASE SUPPORT						
Base, 10^3T/yr	30.00	30.00	30.00	5.00	5.00	5.00
Equip & consum, 10^3T/yr	41.97	41.97	41.97	15.28	15.28	15.28
Persnl consum, 10^3T/yr	84.03	84.03	84.03	38.87	38.87	38.87
COTV flts/yr	520	624	780	12	10	10
HLLV flts/yr	351	368	408	133	140	155
D. LEO BASE SUPPORT						
Base, 10^3T/yr	5.00	5.00	5.00	30.00	30.00	30.00
Equip & consum, 10^3T/yr	6.38	6.38	6.38	33.07	33.07	33.07
Persnl consum, 10^3T/yr	12.76	12.76	12.76	84.23	84.23	84.23
HLLV flts/yr	54	57	63	331	347	386

Construction + Repair
Scenario C'

TABLE VI-F-13 (CONT'D)

YEAR 16 TRANSPORTATION TRAFFIC MODEL
(Preliminary Estimates)

	GEO ASSY MIN	GEO ASSY NOM	GEO ASSY MAX	LEO ASSY MIN	LEO ASSY NOM	LEO ASSY MAX
E. SPS TRANSFER TO GEO						
Total SPS mass, 10^3T/yr	3771.300	3771.300	3771.300	3922.152	4450.521	4714.318
COTV flts/yr	12571	15085	18857	774	774	774
HLLV flts/yr	8475	8895	9873	8814	10497	12341
F. TOTAL COTV REQMT						
GEO cargo mass, 10^3T/yr	3966.883	3980.077	4006.466	4000.914	4535.819	4812.690
Total COTV flts/yr	13223	15920	20032	789	788	790
COTV prop wt, 10^3T/yr	7589.97	9138.26	11498.56	1092.16	1286.71	1893.80
COTV flt cost, $M/yr	22479	41393	78126	56818	69382	79764
COTV fleet size, units	11	16	24	49	49	49
COTV replacement, units	121	302	777	740	739	740
HLLV flts/yr	18107	22894	32013	3920	4786	7315
G. TOTAL HLLV REQMT						
LEO cargo mass, 10^3T/yr	12131.42	13821.81	16425.66	5931.27	6763.88	7832.22
Total HLLV flts/yr	27262	32599	42999	13329	15953	20503
HLLV flt cost, $M/yr	190831	293387	601988	93301	143573	287045
HLLV fleet size, units	23	33	52	11	16	25
HLLV replacement, units	45	75	163	22	37	78
H. TRANSPORTATION COST RECAP						
POTV flt cost, $M/yr	1680	2800	5321	777	1296	2462
PLV flt cost, $M/yr	3226	14517	26130	10465	18468	33242
COTV flt cost, $M/yr	22479	41393	78126	56818	69382	79764
Subtotal	32385	58710	109577	68060	89145	115468
HLLV flt cost, $M/yr	190831	293387	601988	93301	143573	287045
TOTAL TRANSPORTATION COST $M	223217	352097	711564	161361	232718	402513
Specific cost, $/Kg SPS	59.19	93.36	188.68	41.14	52.29	85.38
Specific cost, $/KWe buss	485.25	765.43	1546.88	350.78	505.91	875.03

TABLE VI-F-14

Average SPS Transportation Costs
Construction + Repair*
Scenario C'

Vehicle	Truss - GEO			Truss - LEO		
	Min	Nom	Max	Min	Nom	Max
HLLV	50.60	77.79	159.62	23.79	32.26	60.89
PLV	2.18	3.85	6.93	2.67	4.15	7.05
COTV	5.96	10.98	20.72	14.49	15.59	16.92
POTV	.45	.74	1.41	.21	.29	.52
Total, $/Kg SPS	59.19	93.36	188.68	41.14	52.29	85.39

*Nominal estimates of SPS mass, personnel, consumables, bases.

TABLE VI-F-15

Average SPS Transportation Costs
Construction + Repair*
Scenario C'

Vehicle	Truss - LEO			Truss - LEO		
	Min	Nom	Max	Min	Nom	Max
HLLV	414.85	637.80	1308.67	202.83	312.12	624.01
PLV	17.88	31.56	56.80	22.75	40.15	72.27
COTV	48.87	89.98	169.84	123.52	150.83	173.40
POTV	3.65	6.09	11.57	1.69	2.82	5.35
Total, \$/KWe Buss	485.25	765.43	1546.88	350.79	505.92	875.03

*Nominal estimate of SPS mass, personnel, consumables, bases.

SECTION VI

APPENDIX A

PRELIMINARY DESIGN ANALYSIS

OF A SPACE POWER SATELLITE

HEAVY LIFT LAUNCH SYSTEM

by: ENGINEERING ANALYSIS DIVISION

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CONTRIBUTING ORGANIZATIONS

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PROPULSION AND POWER DIVISION
SPACECRAFT DESIGN DIVISION
STRUCTURES AND MECHANICS DIVISION

1.0 ABSTRACT

A preliminary design launch vehicle having a 30 pound per cubic foot payload density has been sized to deliver the solar power satellite into low earth orbit. The vehicle is a tandem-staged, reusable straight winged launch vehicle capable of delivering a 1-million pound payload to a 270 nautical mile, 5.5 degree inclined circular parking orbit. This launch vehicle has been designated EDIN EX-338-76.

The EDIN EX-338-76 concept used LOX/C_3H_8 booster engines and LOX/LH_2 engines in the upper stage. The weight scaling coefficients were derived from Space Shuttle Phase B System Studies. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflect a 1995 technology level. The second stage used uprated (P_c=4000 PSIA) existing space shuttle main engine (SSME's). The gross liftoff weight of the vehicle was 21,095,563 pounds. The booster stage required 16 x 1.916 million pound vacuum thrust engines; the second stage needed 14 x 544 thousand pound vacuum thrust engines. The vehicle was designed to a liftoff thrust to weight ratio of 1.3. The diameter of each stage was 50 feet.

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2.0 SUMMARY

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 x 270 nautical mile insertion orbit. The vehicle was sized to deliver a 1-million pound payload to the parking orbit when launched due east from a 5 5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 51,390 pound propulsion system.

A 50 foot diameter was assumed for both stages. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies.The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used uprated existing space shuttle main engines (SSME's). A 30 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/C_3H_8 for the booster propellant and moderate chamber pressure (P_c=3000 PSIA) gas generator cycle engines. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH_2 propellant with high chamber pressure (P_c=4000 PSIA) staged combustion cycle engines. These engines were uprated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 75,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 21,095,563 pounds. The booster stage weighed 14,094,797 pounds while the second stage weighed 5,867,823 pounds. The booster required 16 LOX/PROPHNE engines; the second stage required 14 LOX/LH_2 engines. The configuration is summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-338-76.

3.0 INTRODUCTION

Preliminary estimates of the SFS system indicate that an operational power generating satellite will weigh about 200-million pounds in geosynchronous earth orbit. Since most SPS scenarios call for the assembly of up to four operational satellites per year, the number of earth launches is several hundred per year and launch vehicle payloads of 1 million pounds will probably be required.

The transportation system necessary for the implementation of the SPS would require "heavy lift" launch vehicles (HLLV's) to be dedicated, designed, and developed specifically for the SPS mission. In addition, the high launch rate required by the SPS program in some measure dictates the desired characteristics of a launch vehicle; for example, vehicle lifetime, the extent of reusability and operational mode would have a direct bearing on total program costs. This report is part of a parametric study to define variable vehicle concepts to support the SPS.

4.0 METHODS OF ANALYSIS

4.1 ASSUMPTIONS AND GROUND RULES

The assumptions and groundrules for the sizing analysis are presented in figure 1. The analysis may require updates as groundrules and requirements change with program maturity.

4.2 SIZING ANALYSIS

The vehicle stages were sized using WAGERS. The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a TPS consisting of hardened compacted fibers (HCF) bonded to the body structure external to the integral aluminum mainstage propellant tanks. Titanium structure and HCF were used for the aerodynamic surface TPS. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflect a 1995 technology level. The upper stage used uprated (P_c-4000 PSIA) existing space shuttle main engines (SSME's).

4.3 LAUNCH ANALYSIS

All trajectories for this analysis were computed using a 3 degree-of-freedom trajectory program integrating the equations of motion of a particle moving over a rotating oblate spheroid planet under the influence of gravity, thrust, and aerodynamic forces. During first stage flight, the vehicle flew a vertical rise for 16 seconds and then pitched over at a constant inertial pitch rate for 10 seconds. The vehicle then flew a gravity turn trajectory to staging A 4 second coast period was allowed for stage separation. During second stage flight the vehicle was flown using a near optimum linear-tangent steering law to insertion. The vehicle then coasted to apogee of the insertion orbit where the payload was separated from the vehicles second stage. The orbit maneuvering propulsion system (OMPS) circularized the payload at 270 nautical mile. The OMPS for this analysis used a solid rocket motor having a vacuum specific impulse of 300 seconds and a motor mass fraction of 0.80. Saturn V aerodynamic data was used for this preliminary analysis. The reference area used in conjunction with the aerodynamic data was calculated based on the cross-sectional area of the base diameter of the vehicle.

4.4 ENTRY ANALYSIS

The entry trajectory analysis for the booster and second stage were computed using a point mass program to determine major system environments. Vehicle heating rates, ranges, dynamic pressure, loads, and other pertinent trajectory results are given in figures 30-35.

The aerodynamic data for the vehicle wing size and trimmed balance characteristics were generated from Newtonian hypersonic flow theory. The governing criteria for wing sizing is the entry trim requirement and not vehicle landing speed . The first and second stages of the system have c.g.'s in excess of 70% body length aft of the nose. The major reason for the aft c.g. is the heavy engines and thrust structure in the aft end of the vehicle. A canard is used to provide subsonic stability and control. At hypersonic speed it is desired to have the canard at a zero degree angle-of-attack to reduce wing area requirements. Various combinations of canard, body flap, and elevon incidence can be used to provide the control required for a subsonic or hypersonic angle-of-attack transition maneuver.

5.0 RESULTS AND DISCUSSION

5.1 GENERAL VEHICLE

Rocket propulsion system data obtained from Propulsion and Power Division personnel is presented in figure 2. Main booster propellants are LOX and propane with second stage propellants of LOX and hydrogen. System vacuum specific impulses are 340 and 466 seconds, respectively. The booster stage required 16 x 1,916 million pound vacuum thrust engines with the second stage requiring 14 x 544 thousand pound vacuum thrust engines.

Vehicle gross weight and size results are presented in figure 4. Gross lift-off weight for the configuration is 21,095,563 pounds. Booster stage inert weight is 1,349,769 pounds with a propellant load of 12,557,911 pounds. The second stage inert weight is 736,425 pounds with a propellant load of 5,066,640 pounds. Dimensions and gross geometric characteristics of the launch vehicle configuration is presented in figures 6-7.

5.2 BOOSTER STAGE

The booster weights in terms of percent of vehicle empty weight is presented in figure 12. It is apparent from this figure that the greatest percentages are: ascent propulsion, 31.7%, body group, 29.0%, and the wing and tail group, 10.7%. These items make up 71.4% of the stage empty weight. Most of this weight is located in the rear of the stage. This produces an aft c.g. of 75.45% body length. The 75.45% c.g. could be relieved if the propulsion system weights could be reduced or relocated. This data presents an area amenable to engineering work; such work could reduce the vehicle weights and result in a more favorable c.g. location.

5.2.1 GEOMETRY

A geometry summary of the booster stage is presented in figure 8 The system tank volumes are 79,625 cubic feet for fuel and 136,842 cubic feet for oxidizer. The basic vehicle has a slenderness ratio of 5.338. The system length is 266.9 feet with a 50 foot diameter. The basic plan loading is 120 pounds per square foot which has 11,123 square feet of theoretical wing area. The wing area requirement is dictated by hypersonic entry trim and not vehicle landing speed. The booster wing selected has a sweep angle of 44 degrees and an aspect ratio of 3 54. The wing span is 198.43 feet and the wing body chord is 67 feet. The canard has an area of 2,523 square feet with a sweep angle of 0 degrees. The canard span is 91.66 feet at an aspect ratio of 3.33. The vertical tail consists of a single fin located at the aft end of the body. The total vertical tail area is 2,610 square feet. The aerodynamic surfaces have not been optimized, but have been selected to provide a workable baseline. Improvements can be made at a later vehicle iteration cycle. The booster configuration and its pitch trim aerodynamics are presented in figures 9-10. In order to keep wing areas lower, a 75,000 pound ballast in the booster nose was used. This ballast can possibly be traded against a reusable interstage at a later date when the vehicle's interstage might be designed for reuse. The vehicle landing speed is estimated to be 180 knots. The booster detailed weight statement for subsystem and component weights is presented in figure 11. They are generated and described as weight fractions developed from the WAGERS.

5.2.2 AEROSURFACE GROUP

The booster wing weight has been determined as 116,859 pounds. The canard and vertical tail weights are 9,217 and 13,353 pounds, respectively. An auxilliary body flap for trim is estimated to weigh 8,750 pounds. The total aerosurface group will require more detailed analysis to determine the optimum surface size, material design, and construction techniques. The current analysis is an exponential function of empty weight, load factor, area span, and inversly proportional to root thickness. These data have been obtained from historical results and applied emperical techniques. The canard and vertical tail area have been selected proportional to body surface area. The coefficients applied to the canard area was 3.65 pounds per square foot of theoretical area and the vertical tail was 5.12 pounds per square foot. The body flap surface used 7 pounds per square foot as the weight scaling factor.

5.2.3 BODY GROUP

The booster body group weights are presented in figure 11. The body group includes tanks, thrust structure, skirts, bulk heads, tank domes and other structural components. The total group weighs 379,674 pounds with the LOX tank weighing 86,391 pounds and fuel tank weighing 50,269 pounds. Detailed structural analysis must be used to update these weights. These data have been obtained from emperical results of historical data. The nose structure, forward skirt, inner tank, and base skirt are determined as a function of surface area. The mainstage propellant tank weights are determined directly proportional to tank volume. The aft skirt and thrust structure are determined directly proportional to the vacuum thrust of the stage.

5.2.4 THERMAL PROTECTION SYSTEM

The booster TPS weight breakdown is presented in figure 11 . The gross system weighs 63,447 pounds . The body structure, tanks, and other main fuselage components are considered to be heatsink. In this study the wing, canard, and vertical tail were considered to have HCF insulation with titanium panels applied at local hot spots. These weight data were obtained as directly proportional values of surface area.

5.2.5 LANDING SYSTEM

The gross landing system weights are 55,203 pounds and are presented in figure 11. Detailed analysis wil be required for substantiation of these data. The current analysis considers the landing system weight as linearly proportional to the landed weight. These data have been obtained from extrapolated historical data.

5.2.6 ASCENT PROPULSION GROUP

The ascent propulsion group consists of main engines, accessories, gimbal systems and fuel and oxidizer system. The weights are presented in figure 11. The group weighs 415,396 pounds. These data were obtained from Propulsion and Power Division personnel.

5.2.7 AUXILLIARY PROPULSION GROUP

The auxilliary propulsion system weight is estimated to be 10,986 pounds and is shown in figure 11. These data have been scaled linearly proportional to the stage entry weight. These data have been obtained from historical results.

5.2.8 PRIME POWER SYSTEM

The prime power system weight estimate is 3,881 pounds and is shown in figure 11. This data was determined from WAGERS and considered to be linearly proportional to vehicle landed weight.

5.2.9 ELECTRICAL CONVERSION AND DISTRIBUTION SYSTEM

The electrical system is estimated to weigh 1,818 pounds and is shown in figure 11. These data were estimated from WAGERS and is considered to be a constant weight.

5.2.10 HYDRAULIC CONVERSION AND DISTRIBUTION SYSTEM

The hydraulic conversion and distribution system is estimated to weigh 15,939 pounds and is shown in figure 11. These data were estimated from WAGERS and are obtained directly proportional to vehicle landed weight.

5.2.11 AEROSURFACE CONTROLS

The aerosurface controls are estimated to weigh 21,746 pounds and are shown in figure 11. These data are estimated from WAGERS and historical data. Each surface control is considered directly proportional to it's own theoretical surface area.

5.2.12 ENVIRONMENTAL SYSTEM

The environmental control system is estimated to be 0 pounds as shown in figure 11 since the current requirement is for an unmanned system

5.2.13 AVIONICS SYSTEM

The avionics system weight is estimated to be 4,900 pounds and is shown in figure 11. These data are estimated from WAGERS and historical data. For this study it is assumed to be a constant weight.

5.2.14 PERSONNEL PROVISIONS

Currently personnel provisions are estimated to weigh 0 pounds as shown in figure 11. Current groundrules require an unmanned operation.

5.2.15 PROPELLANT LOSSES AND LOADINGS

Empty vehicle weights and various propellant losses and loadings are presented in figure 11 and are estimated to be 27,392 pounds for residuals, 198,002 pounds for inflight losses, 2,515 pounds for RCS, and 236,322 pounds for preignition propellant.

5.3 SECOND STAGE

The second stage weights in terms of percent of vehicle empty weight is presented in figure 18. It is apparent from this figure that the greatest percentages are: ascent propulsion, 17.7%, body group, 34.0%, and wing and tail groups, 11.98%. These items make up 63.7% of the stage empty weight. Most of this weight is located in the rear of the stage. This produces an aft c.g. of 72.5% body length. However, this aft c.g. is not as severe as the booster c.g. so no ballast is required in the nose of the second stage.

5.3.1 GEOMETRY

A geometry summary of the second stage is presented in figure 14. The system tank volumes are 174,099 cubic feet for fuel and 63,751 cubic feet for oxidizer. The stage has a slenderness ratio of 5.004. The system length is 250.19 feet; its diameter is 50 feet. The basic plan loading is 98.8 pounds per square foot which has 7,368.9 square feet of theoretical wing area. The wing area requirement is dictated by hypersonic entry trim and not vehicle landing speed. The second stage wing selected has a sweep angle of 44 degrees and an aspect ratio of 3.54. The wing span is 161.51 feet and the wing body chord is 52.47 feet. The canard has an area of 2,353.2 square feet with a sweep angle of 0 degrees. The canard span is 88.52 feet at an aspect ratio of 3.33. The vertical tail consists of a single fin located at the aft end of the body. The total vertical tail area is 2,433.9 square feet. The aerodynamic surfaces have not been optimized, but have been selected to provide a workable baseline. The second stage configuration and its pitch trim aerodynamics are presented in figures 15-16. The vehicle landing speed is estimated to be 180 knots. The second stage detailed weight statement for subsystem and component weights is presented in figure 17. There are no detailed design descriptions of subsystems. They are generated and described as weight fractions developed from WAGERS.

5.3.2 AEROSURFACE GROUP

The second stage wing weight has been determined as 64,253 pounds The canard and vertical tail weights are 8,597 and 12,454 pounds, respectively. An auxilliary body flap for trim is estimated to weigh 8,750 pounds. The total aerosurface group will require more detailed analysis to determine the optimum surface size, material design, and construction techniques. The current analysis is an exponential function of empty weight, load factor, area span, and inversly proportional to root thickness. These data have been obtained from historical results and applied emperical techniques. The canard and vertical tail area have been selected proportional to body surface area. The coefficients applied to the canard area was 3.65 pounds per square foot of theoretical area and the vertical tail was 5.12 pounds per square foot. The body flap surface used 7 pounds per square foot as the weight scaling factor.

5.3.3 BODY GROUP

The second stage body group weights are presented in figure 17. The body group includes tanks, thrust structure, skirts, bulk heads, tank domes and other structural components. The total group weighs 242,338 pounds with the LOX tank weighing 27,647 pounds and fuel tank weighing 99,583 pounds. Detailed structural analysis must be used to update these weights. These data have been obtained from emperical results of historical data The nose structure, forward skirt, inner tank, and base skirt are determined as a function of surface area. The mainstage propellant tank weights are determined directly proportional to tank volume. The aft skirt and thrust structure are determined directly proportional to the vacuum thrust of the stage.

5.3.4 THERMAL PROTECTION SYSTEM

The second stage TPS weight breakdown is presented in figure 17. The gross system weight is 116,237 pounds. In this study the body, wing, canard, and vertical tail were considered to have HCF surface insulation with titanium panels applied at local hot spots. These weight data were obtained as directly proportional values of surface area. In addition the hydrogen tank required internal foam insulation.

5.3.5 LANDING SYSTEM

The gross landing system weights are 29,922 pounds and are presented in figure 17. Detailed analysis wil be required for substantiation of these data. The current analysis considers the landing system weight as linearly proportional to the landed weight. These data have been obtained from extrapolated historical data.

5.3.6 ASCENT PROPULSION GROUP

The ascent propulsion group consists of main engines, accessories, gimbal systems and fuel and oxidizer system. The weights are presented in figure 17. The group weighs 125,738 pounds. These data were obtained from Propulsion and Power Division personnel.

5.3.7 AUXILLIARY PROPULSION GROUP

The auxilliary propulsion system weight is estimated to be 5,678 pounds and is shown in figure 17. These data have been scaled linearly proportional to the stage entry weight. These data have been obtained from historical results.

5.3.8 PRIME POWER SYSTEM

The prime power system weight estimate is 2,104 pounds and is shown in figure 17. This data was determined from WAGERS and considered to be linearly proportional to vehicle landed weight.

5.3.9 ELECTRICAL CONVERSION AND DISTRIBUTION SYSTEM

The electrical system is estimated to weigh 1,818 pounds and is shown in figure 17. These data were estimated from WAGERS and is considered to be a constant weight.

5.3.10 HYDRAULIC CONVERSION AND DISTRIBUTION SYSTEM

The hydraulic conversion and distribution system is estimated to weigh 8,640 pounds and is shown in figure 17. These data were estimated from WAGERS and are obtained directly proportional to vehicle landed weight.

5.3.11 AEROSURFACE CONTROLS

The aerosurface controls are estimated to weigh 16,101 pounds and are shown in figure 17. These data are estimated from WAGERS and historical data. Each surface control is considered directly proportional to it's own theoretical surface area.

5.3.12 ENVIRONMENTAL SYSTEM

The environmental control system is estimated to be 0 pounds as shown in figure 17 since the current requirement is for an unmanned system.

5.3.13 AVIONICS SYSTEM

The avionics system weight is estimated to be 4,900 pounds and is shown in figure 17 . These data are estimated from WAGERS and historical data. For this study it is assumed to be a constant weight.

5.3.14 PERSONNEL PROVISIONS

Currently personnel provisions are estimated to weigh 0 pounds as shown in figure 17. Current groundrules require an unmanned operation.

5.3.15 PROPELLANT LOSSES AND LOADINGS

Empty vehicle weights and various propellant losses and loadings are presented in figure 17 and are estimated to be 15,625 pounds for residuals, 71,534 pounds for inflight losses, 1,311 pounds for RCS, and 22,294 pounds for preignition propellant.

5.4 ASCENT TRAJECTORY

Ascent trajectory data are presented in figures 20-29. Pertinent parameters of most interest are:

Max G Booster = 3.6
Max G Second Stage = 4.0
Max Q = 783.5 psf
Max Heating Rate = 17.5 BTU/SQ FT/SEC
Max Heat Load = 1,810.9 BTU/SQ FT

Staging Conditions

Time = 138.3 Sec
Relative Velocity = 6,149 fps
Relative Flight Path Angle = 17.86 deg.
Altitude = 143,943 Feet

5.5 ENTRY TRAJECTORY

The basic point mass entry trajectory profiles are presented in figures 30-35.

The major trajectory parameters for the booster stage are:

Max Q = 121 psf
Max G = 4.9
Down Range = 181 n. mi.
Max Heat Load = 427 BTU/SQ. FT.
Max Heat Rate = 3.6 BTU/SQ. FT./SEC

The major trajectory parameters for the second stage entry are:

Max Q = 49 psf
Max G = 1.86
Down Range = 5,374 n. mi.
Max Heat Load = 38,618 btu/sq. ft.
Max Heat Rate = 52 btu/sq. ft. ...

FIGURE 1. ASSUMPTIONS AND GROUNDRULES

* TWO-STAGE STRAIGHT WINGED REUSABLE TANDEM-STAGED LAUNCH VEHICLE
* HEATSINK BOOSTER
* 1 MILLION POUND PAYLOAD (DOES NOT INCLUDE MANEUVERING PROPULSION SYSTEM)
* PAYLOAD BAY FILL EFFICIENCY WAS 60%
* PAYLOAD DENSITY IS 30 POUNDS PER CUBIC FOOT
* PAYLOAD LOCATED IN FORWARD NOSE STRUCTURE
* VEHICLE SIZED FOR DUE EAST LAUNCH FROM 5.5 DEGREES LATITUDE SITE
* 50 x 270 NM INSERTION ORBIT (270 NM CIRCULAR PARKING ORBIT)
* PHASE B SPACE SHUTTLE WEIGHT AND GEOMETRY TECHNOLOGY USED FOR WEIGHT SCALING
* 10 PERCENT DRY WEIGHT CONTINGENCY ADDED ON BOTH STAGES
* NO AIR BREATHING ENGINES ON EITHER STAGE
* 50 FT. DIAMETER STAGES
* NO MAX Q CONSTRAINT
* 4 G MAXIMUM ACCELERATION LIMIT
* LOX/PROPANE PROPELLANT USED IN BOOSTER STAGE
* LOX/LH2 PROPELLANT USED IN SECOND STAGE
* BOOSTER PROPULSION SYSTEM WEIGHTS AND PERFORMANCE DATA REFLECTS 1995 TECHNOLOGY LEVEL
* SECOND STAGE USED UPRATED EXISTING SPACE SHUTTLE MAIN ENGINE
* BOOSTER T/W = 1.3, SECOND STAGE T/W = 1.1
* LANDING SPEED FOR BOTH STAGES IS APPROXIMATELY 180 KNOTS
* SATURN V LAUNCH VEHICLE AERODYNAMIC DATA ESTIMATES
* FPR PROPELLANT CALCULATED BASED ON RESERVING 0.75% OF TOTAL IDEAL VELOCITY

FIGURE 2. ROCKET ENGINE PROPULSION SYSTEM PARAMETERS

PARAMETER	STAGE 1	STAGE 2
PROPELLANT	LOX/C3H8	LOX/LH2
MIXTURE RATIO (OF)	2.68:1	6.00:1
CHAMBER PRESSURE (PSIA)	3000.0	4000.0
ENGINE OPERATION CYCLE	GAS GENERATOR	STAGED COMBUSTION
EXPANSION RATIO (AE/AT)	40.0	200.0
VACUUM SPECIFIC IMPULSE (SEC)	340.00	466.0
SEA LEVEL SPECIFIC IMPULSE (SEC)	304.11	-----
FUEL DENSITY (LBS/CUFT)	46.50	4.42
OXIDIZER DENSITY (LBS/CUFT)	71.38	71.38
FUEL STORAGE TEMPERATURE (DEG F)	-297.0	-420.0
OXIDIZER STORAGE TEMPERATURE (DEG F)	-297.0	-297.0

FIGURE 3. LIQUID ROCKET ENGINE DATA

PARAMETER	STAGE 1	STAGE 2
NUMBER OF ENGINES	16.0	14.0
VACUUM THRUST ENGINE (LBS)	1916292 7	543924.3
VACUUM ISP (SEC)	340.00	466.00
SEA LEVEL THRUST/ENGINE (LBS)	1714014.4	341334.8
SEA LEVEL ISP (SEC)	304.11	292.43
EXIT AREA/ENGINE (SQ IN)	13713.0	13734.1
ENGINE WEIGHT (LBS)	19162.9	8118.3

FIGURE 4. VEHICLE SUMMARY WEIGHT BREAKDOWN

ITEM		WEIGHT (LBS)
PRE-IGNITION WEIGHT		21331885.
PRE-IGNITION PROPELLANT	236322	
GROSS LIFTOFF WEIGHT		21095563.
BOOSTER LIFTOFF WEIGHT		14094797.
MAINSTAGE PROPELLANT	12557911	
INERT WEIGHT (LESS CONT)	1349769	
DRY WEIGHT CONTINGENCY	112117.	
BALLAST	75000.	
INTERSTAGE (INCL SEP SYS)		59313
SECOND STG THRUST BUILDUP PROPT		22294.
SECOND STG LIFTOFF WEIGHT		5967823.
MAINSTAGE PROPELLANT (INCL FPR)	5066640	
INERT WEIGHT (LESS CONT)	736425.	
DRY WEIGHT CONTINGENCY	64758	
PAYLOAD (DESIGN =1000000.0)		999957.
ORBITAL MANEUVERING SYSTEM		51390

FIGURE 5. LAUNCH VEHICLE TRAJECTORY PARAMETER SUMMARY

PARAMETER	STAGE 1	STAGE 2
IDEAL VELOCITY (FPS)	9581.9	29036.9
RELATIVE FLIGHT PATH ANGLE (DEG)	17.86	.17
RELATIVE VELOCITY (FPS)	6148.9	24595.2
INERTIAL FLIGHT PATH ANGLE (DEG)	14.33	.16
INERTIAL VELOCITY (FPS)	7619.1	26136.4
ALTITUDE (FT)	143943.2	307005.2
BURN TIME (SEC)	139.3	451.6
RANGE (NM)	35.9	690.9
MAXIMUM DYNAMIC PRESSURE (PSF)	783.5	----
BURNOUT DYNAMIC PRESSURE (PSF)	83.4	----
INITIAL ACCELERATION (G)	1.3	1.1
BURN OUT ACCELERATION (G)	3.6	4.0

FIGURE 6. MATED CONFIGURATION GEOMETRY

TOTAL VEHICLE LENGTH		519.1
BOOSTER LENGTH		266.9
BOOSTER DIAMETER	50.0	
BOOSTER WING SPAN	198.4	
BOOSTER WING AREA	11123.3	
BOOSTER CANARD SPAN	91.7	
BOOSTER CANARD AREA	2523.0	
DIFFERENCE BETWEEN STAGES		2 0
SECOND STAGE LENGTH		250.2
SECOND STAGE DIAMETER	50.0	
SECOND STAGE WING SPAN	161.5	
SECOND STAGE WING AREA	7368.9	
SECOND STAGE CANARD SPAN	88.5	
SECOND STAGE CANARD AREA	2353.2	

FIGURE 7 MATED CONFIGURATION PLAN FORM VIEW

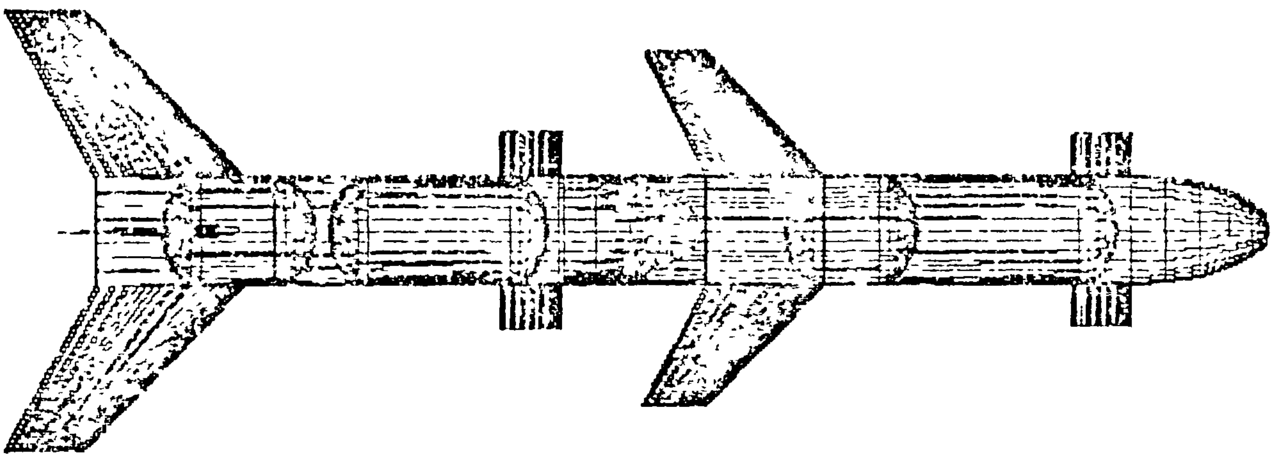

FIGURE 7A MATED CONFIGURATION SIDE VIEW

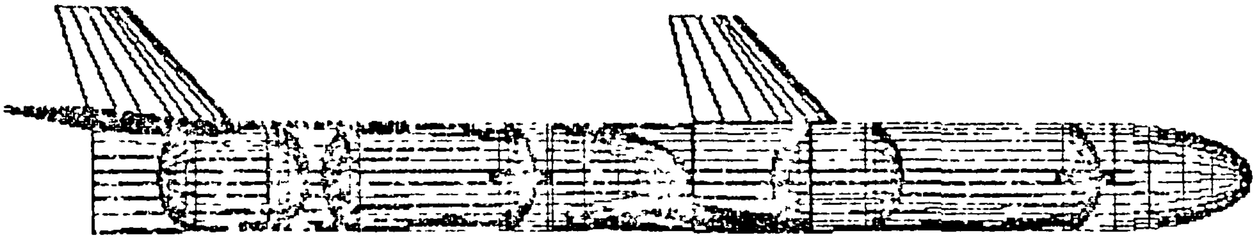

FIGURE 7B MATED CONFIGURATION FRONTAL VIEW

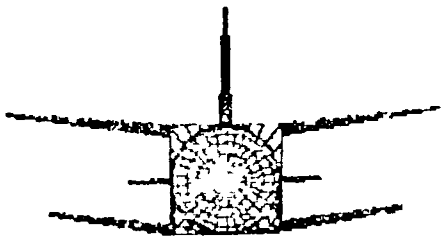

FIGURE 7C MATED CONFIGURATION ORTHOGONAL VIEW

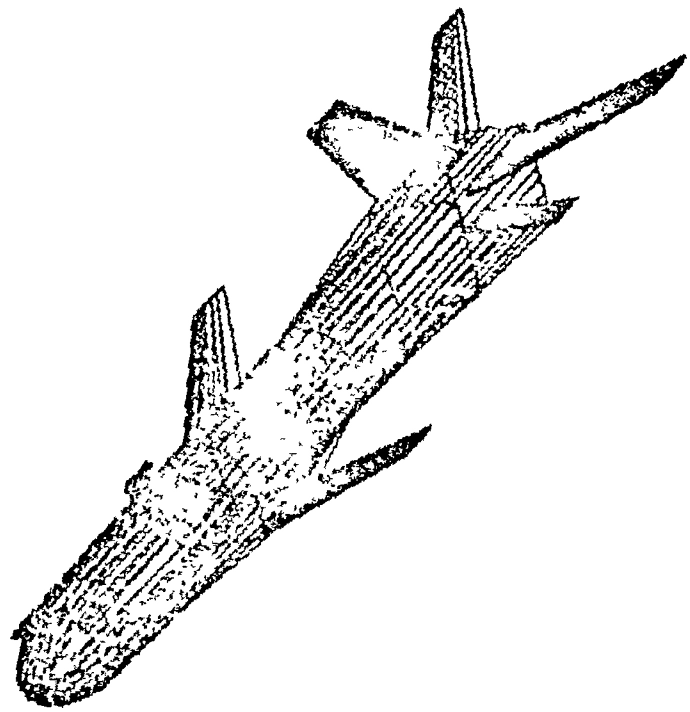

FIGURE 8. LIQUID ROCKET BOOSTER GEOMETRY SUMMARY

LOX TANK VOLUME		136842.	
FUEL TANK VOLUME		79625.	
BODY WETTED SURFACE AREA		28997.	
STAGE SLENDERNESS RATIO			5.3360
TOTAL STAGE LENGTH		266.90	
AFT DIAMETER		50.00	
STAGE DIAMETER		50.00	
BASE SKIRT LENGTH	18.45		
AFT SKIRT LENGTH	28.68		
FUEL TANK AFT BKD LENGTH	17.68		
FUEL TANK BARREL LENGTH	33.05		
FUEL TANK FWD BKD LENGTH	17.68		
LOX TANK AFT BKD LENGTH	17.68		
LOX TANK BARREL LENGTH	62.19		
LOX TANK FWD BKD LENGTH	17.68		
FWD SKIRT LENGTH	22.68		
FWD NOSE LENGTH	62.50		
INTERSTAGE LENGTH	64.50		
INTERSTAGE AFT DIAMETER	50.00		
INTERSTAGE FWD DIAMETER	50.00		
WING LOADING		120.08	
THEORETICAL WING AREA		11123.3	
EXPOSED WING AREA		7495.1	
LEADING EDGE SWEEP ANGLE		44.00	
TRAILING EDGE SWEEP ANGLE		27.51	
WING ASPECT RATIO		3.5400	
WING TAPER RATIO		.43500	
GEOMETRIC WING SPAN		198.43	
STRUCTURAL WING SPAN		247.24	
WING ROOT CHORD		78.13	
WING BODY CHORD		67.00	
WING TIP CHORD		33.98	
ELEVON AVERAGE CHORD		15.15	
CANARD THEO. AREA		2523.0	
CANARD EXPOSED AREA		1146.7	
WING ROOT THICKNESS		8.3594	
WING CENTROID OF AREA		71.095	
CANARD ASPECT RATIO		3.3300	
CANARD TAPER RATIO		1.00000	
CANARD GEOMETRIC SPAN		91.66	
CANARD ROOT CHORD		27.53	
CANARD TIP CHORD		27.53	
VERT TAIL THEO. AREA		2609.6	
BODY FLAP CHORD		25.00	
BODY FLAP AREA		1250.0	

NOTE - ALL DIMENSIONS ARE GIVEN IN FEET
ALL AREAS ARE GIVEN IN SQUARE FEET
ALL VOLUMES ARE GIVEN IN CUBIC FEET

FIGURE 9

BOOSTER HYPERSONIC TRIM DATA

***** REFERENCE DIMENSIONS *****

AREA=11123.28 LENGTH= 266.90

*** BODY ***	*** WING ***	*** CANARD ***
RADIUS= 25.00	EXP A= 7495.06	EXP A= 1146.75
LENGTH=266.90	BODY C= 67 00	BODY C= 27.53
NOSE L= 62.50	TIP C= 33.98	TIP C= 27.53
NOSE=CONE	X LE BC= 134.90	X LE BC= 62.50
	SPAN= 148 43	SPAN= 91.66
	SWEEP= 44.00	SWEEP= 00
		INCIDENCE=-15 00

	* WING ELEVON *	* BODY FLAP *
	CHORD= 15 15	A= 1250 00
XCG LB- .7545	DEFLECTION= .00	L= 25.00
		ANGLE= 00

ALPHA	CN B	CN BF	CN C	CN W	CM B	CM BF	CM C	CM W	CNT	CMT
25	.2504	040	0062	.2407	1046	- 012	.00[illegible]	- 0510	6429	.0319
30	3214	056	0138	3369	1269	- 016	.0065	-.0714	8755	.0294
35	3964	.074	.0241	4434	1577	- 022	.0113	-.0940	1 1715	0256
40	4735	093	0368	.5569	1755	- 027	.0172	-.1181	1.4032	.0207
45	5505	112	0515	6738	2026	- [illegible]	0242	-.1429	1 6[illegible]	.0149
50	6252	132	0672	7903	2253	- 039	0318	.1677	1.9614	.0054
55	6952	.151	.0852	.9043	2450	- 044	0[illegible]	-.1917	2.2307	0015
60	7535	.169	1031	1 0107	.2627	049	.0433	2143	2 4826	-.0051
65	8132	.185	1210	1 1069	2723	- 054	.0562	-.2347	2.7095	-.0130
70	.8575	198	1384	1 1900	2893	- 058	.0643	- 2523	2 9044	-.0200
75	8903	210	1546	1 2574	2962	- 061	.0725	- 2666	3 0615	-.0266
80	9104	.213	.1694	1 2070	2989	- 064	0794	- 2771	3 1759	-.0326
85	9172	.213	.1821	1 [illegible]374	2973	- 065	0854	-.2836	3.2442	-.0379

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FIGURE 10 BOOSTER PLAN FORM VIEW

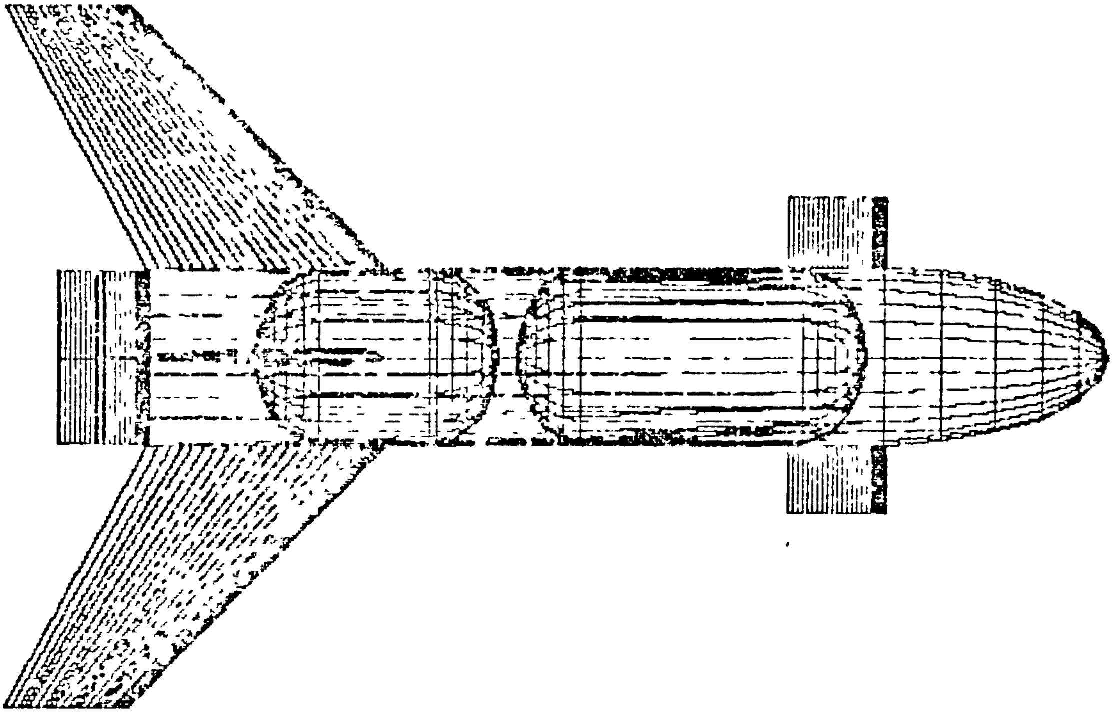


FIGURE 10A BOOSTER SIDE VIEW

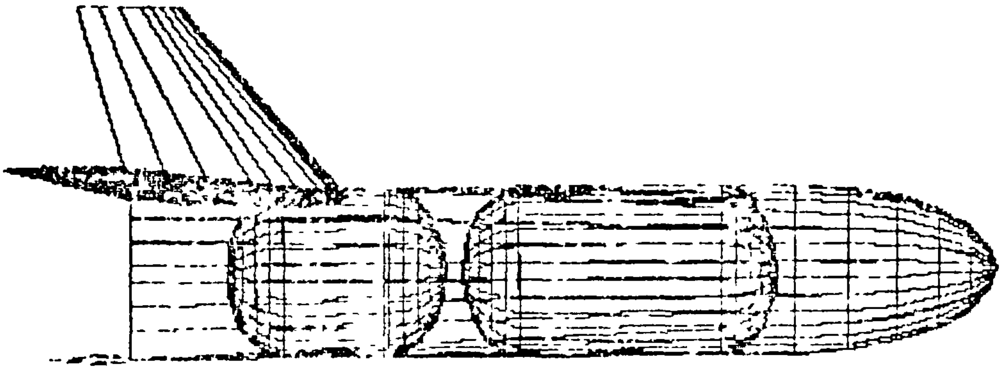


FIGURE 10B BOOSTER FRONTAL VIEW

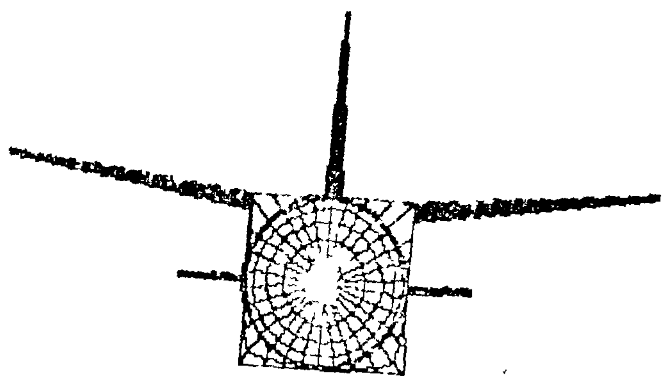


FIGURE 10C BOOSTER ORTHOGONAL VIEW

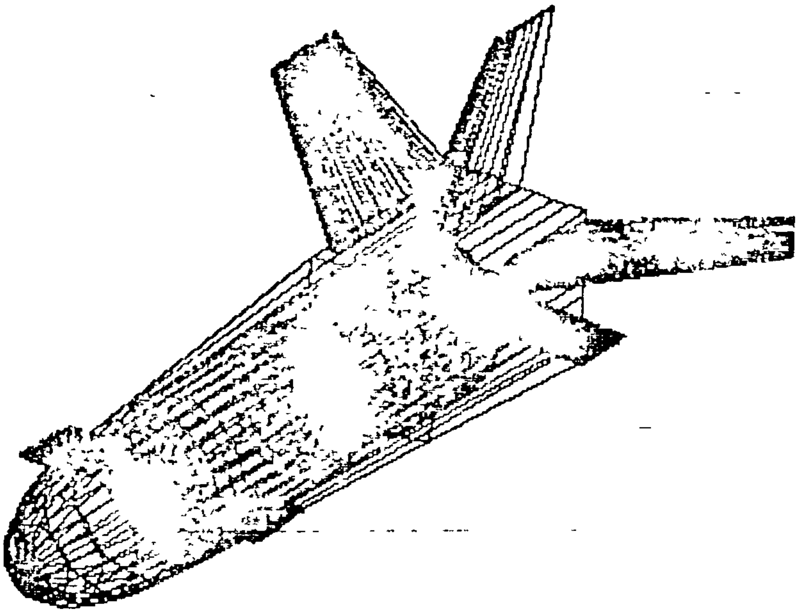


FIGURE 11. LIQUID ROCKET BOOSTER WEIGHT STATEMENT

WING GROUP		116859.	
TAIL GROUP		22570.	
CANARD	9217.		
VERTICAL	13353.		
BODY FLAP		8750.	
BODY GROUP		379674.	
NOSE (INC TPS)	43747.		
FWD SKIRT	19592.		
LOX TANK	86391.		
INTERTANK	39987.		
FUEL TANK	50269.		
AFT SKIRT	0.		
THRUST STRUCTURE	122300.		
BASE SKIRT	17359.		
THERMAL PROTECTION		63447.	
BODY ENTRY TPS	0.		
FLAME SHIELD	13035.		
LOX TANK INSULATION	0.		
INTERTANK INSULATION	0.		
FUEL TANK INSULATION	0.		
WING TPS	30395.		
CANARD TPS	6754.		
VERT TAIL TPS	9847.		
BODY FLAP TPS	0.		
LANDING SYSTEM		55203.	
NOSE GEAR	4490.		
MAIN GEAR	50713.		
DROUGE CHUTE	0.		
ASCENT PROPULSION		415396.	
MAIN ENGINES	306607.		
ACCESSORIES	0.		
GIMBAL SYSTEM	43538.		
FUEL SYSTEM	3060.		
OXIDIZER SYSTEM	62190.		
AUX. PROP. SYS.		10986.	
PRIME POWER		3881.	
ELECT CONV AND DISTR		1818.	
HYDRAULIC CONV AND DSTR		15939.	
AERO SURFACE CONTROLS		21746.	
WING SURFACE CONTROLS	15922.		
CANARD SURFACE CONTROLS	864.		
VERT TAIL SURFACE CONTROLS	3171.		
BODY FLAP CONTROLS	1789.		
AVIONICS		4900.	
ENVIRONMENTAL CONTROL		0.	
PERSONNEL PROVISIONS		0.	
DRY WEIGHT			1121169.
CONTINGENCY		112117.	
BALLAST		75000.	

LIQUID ROCKET BOOSTER WEIGHT STATEMENT (CON'T)

EMPTY WEIGHT			1308286.
RESIDUAL FLUIDS		27392.	
OXID PRESS GASSES	14211.		
FUEL PRESS GASSES	1403.		
RCS	0.		
PRIME POWER	0.		
HYDRAULIC FLUIDS	11778.		
LANDING WEIGHT			1335678
MPS INFLIGHT LOSSES		198002.	
PRIME POWER PROPELLANT		691.	
RESERVES		0.	
ENTRY WEIGHT			1534371.
RCS PROPELLANT		2515.	
FWD INTERSTAGE OR PAYLOAD ADAPTER		55724	
SEPERATION SYSTEM		3589.	
JETTISON WEIGHT AT MPS CUTOFF			1596199.
MAINSTAGE PROPELLANT		12557911.	
MAINSTAGE OXIDIZER	9145435.		
MAINSTAGE FUEL	3412476.		
BOOSTER LIFTOFF WEIGHT			14154110.
PRE-IGNITION PROPELLANT		236322.	
STAGE PRE-IGNITION WEIGHT			14390432
BOOSTER MASS FRACTION			.88723
TOTAL LOX WEIGHT		9453991.	
TOTAL FUEL WEIGHT		3517454.	

(*) ALL WEIGHTS ARE IN POUNDS

FIGURE 12. BOOSTER WEIGHTS AS A % OF EMPTY WEIGHT

ITEM	PCT
WING GROUP	8.932
TAIL GROUP	1.725
BODY FLAP	.669
BODY GROUP	29.021
THERMAL PROTECTION	4.850
LANDING SYSTEM	4.220
ASCENT PROPULSION	31.751
AUX. PROPULSION SYSTEM	.840
PRIME POWER	.297
ELECT CONV AND DISTR	.139
HYDRAULIC CONV AND DISTR	1.218
AERO SURFACE CONTROLS	1.662
AVIONICS	.375
ENVIRONMENTAL CONTROL	.000
PERSONNEL PROVISIONS	.000
DRY WEIGHT	85.698
DESIGN RESERVE CONTINGENCY	8.570
BALLAST	5.733
EMPTY WEIGHT	100.000

FIGURE 13. BOOSTER CG DATA

ITEM	AFT STA *	WEIGHT	X CG *
FORWARD NOSE1 STRUCTURE	62.50	43746.58	36.79
BALLAST	.00	75000.00	5.00
FORWARD SKIRT	85.18	19592.10	73.84
LOX TANK	165.05	86390.92	116.27
LOX TANK PRESSURANT	.00	14210.97	116.27
FUEL TANK	237.45	50266.67	203.25
FUEL TANK PRESSURANT	.00	1402.67	203.25
INTERTANK STRUCTURE	186.72	39987.09	167.05
LOX TANK INSULATION	.00	.00	116.27
FUEL TANK INSULATION	.00	.00	203.25
INTERTANK INSULATION	.00	.00	.00
BASE SKIRT	266.90	17388.72	257.68
BODY FLAP	291.90	8750.00	279.40
TOTAL STAGE	266.90	1179158.67	201.39

STAGE XCG (PCT LB) 75.454

(*) ALL STATIONS AND CENTERS OF GRAVITY ARE GIVEN IN FEET LOCATED AFT OF STAGE NOSE

FIGURE 14. LAUNCH VEHICLE SECOND STAGE GEOMETRY SUMMARY

LOX TANK VOLUME		63751.	
FUEL TANK VOLUME		174099	
BODY WETTED SURFACE AREA		36371.	
PAYLOAD VOLUME		33333.	
PAYLOAD BAY VOLUME	0.		
FWD NOSE VOLUME		61359.	
STAGE SLENDERNESS RATIO			5.0038
TOTAL STAGE LENGTH		250.19	
AFT DIAMETER		50.00	
STAGE DIAMETER		50.00	
BASE SKIRT LENGTH	22.70		
AFT SKIRT LENGTH	28.68		
LOX TANK AFT BHD LENGTH	17.68		
LOX TANK BARREL LENGTH	24.97		
LOX TANK FWD BHD LENGTH	17.68		
FUEL TANK AFT BHD LENGTH	17.68		
FUEL TANK BARREL LENGTH	88.67		
FUEL TANK FWD BHD LENGTH	17.68		
FWD SKIRT LENGTH	22.69		
PAYLOAD BAY LENGTH	.00		
FWD NOSE LENGTH	62.50		
INTERSTAGE LENGTH	.00		
INTERSTAGE AFT DIAMETER	50.00		
INTERSTAGE FWD DIAMETER	50.00		
WING LOADING		96.79	
THEORETICAL WING AREA		7368.9	
EXPOSED WING AREA		4467.6	
LEADING EDGE SWEEP ANGLE		44.00	
TRAILING EDGE SWEEP ANGLE		27.51	
WING ASPECT RATIO		3.5400	
WING TAPER RATIO		.43500	
GEOMETRIC WING SPAN		161.51	
STRUCTURAL WING SPAN		201.24	
WING ROOT CHORD		63.59	
WING BODY CHORD		52.47	
WING TIP CHORD		27.66	
ELEVON AVERAGE CHORD		12.02	
CANARD THEO. AREA		2353.2	
CANARD EXPOSED AREA		1024.0	
WING ROOT THICKNESS		6.8040	
WING CENTROID OF AREA		57.866	
CANARD ASPECT RATIO		3.3300	
CANARD TAPER RATIO		1.00000	
CANARD GEOMETRIC SPAN		88.52	
CANARD ROOT CHORD		26.58	
CANARD TIP CHORD		26.58	
VERT TAIL THEO. AREA		2433.9	
BODY FLAP CHORD		25.00	
BODY FLAP AREA		1250.0	

NOTE - ALL DIMENSIONS ARE GIVEN IN FEET
ALL AREAS ARE GIVEN IN SQUARE FEET
ALL VOLUMES ARE GIVEN IN CUBIC FEET

FIGURE 15

SECOND STAGE HYPERSONIC TRIM DATA

***** REFERENCE DIMENSIONS *****

AREA= 7368.92 LENGTH= 250.19

*** BODY ***	*** WING ***	*** CANARD ***
RADIUS= 25.00	EXP A= 4467.56	EXP A= 1024.03
LENGTH=250.19	BODY C= 52.47	BODY C= 26.58
NOSE L= 62.50	TIP C= 27.66	TIP C= 26.58
NOSE=CONE	X LE BC= 197.72	XLE BC= 62.50
	SPAN= 161.51	SPAN= 88.52
	SWEEP= 44.00	SWEEP= .00
		INCIDENCE=-18.50

	* WING ELEVON *	* BODY FLAP *
	CHORD= 12.02	A= 1250.00
XCG/LB= .7255	DEFLECTION= .00	L= 25.00
		ANGLE= .00

ALPHA	CN B	CN BF	CN C	CN W	CM B	CM BF	CM C	CM W	CNT	CMT
25	.3494	.061	.0036	.2166	.1396	-.020	.0015	-.0528	7966	.0458
30	.4447	.065	.0110	.3031	.1706	-.028	.0047	-.0739	1.0766	.0419
35	5451	.112	.0224	.3989	2021	-.036	.0095	-.0973	1.3646	.0360
40	.6479	.140	.0373	.5010	.2334	-.045	.0158	-.1222	1.7114	.0287
45	.7501	.170	.0553	.6063	.2635	-.055	.0234	-.1479	2.0473	.0200
50	.8486	.199	.0759	.7115	.2916	-.065	.0321	-.1735	2.3521	.0105
55	.9409	.228	.0983	.8136	.3169	-.074	.0416	-.1984	2.7058	.0003
60	1.0237	.254	.1220	.9094	.3386	-.083	.0516	-.2218	3.0084	-.0101
65	1.0946	.279	.1462	.9960	.3560	-.090	.0618	-.2429	3.2809	-.0205
70	1.1516	.300	.1702	1.0707	.3687	-.097	.0719	-.2611	3.5150	-.0306
75	1.1929	.317	.1933	1.1313	.3762	-.103	.0817	-.2759	3.7035	-.0400
80	1.2173	.329	.2147	1.1760	.3784	-.107	.0907	-.2868	3.8407	-.0484
85	1.2240	.337	.2337	1.2033	.3752	-.109	.0988	-.2935	3.9225	-.0557

FIGURE 16 SECOND STAGE PLAN FORM VIEW

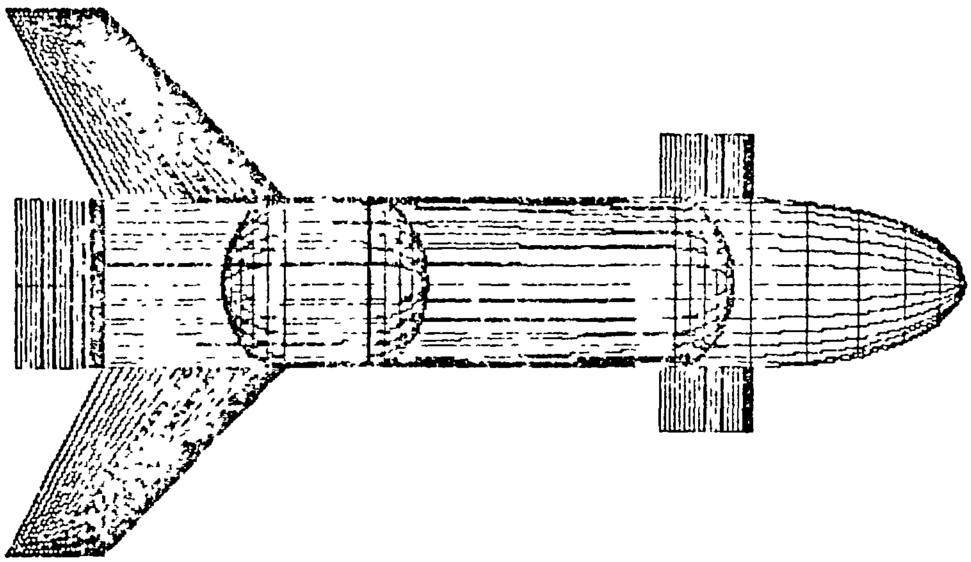
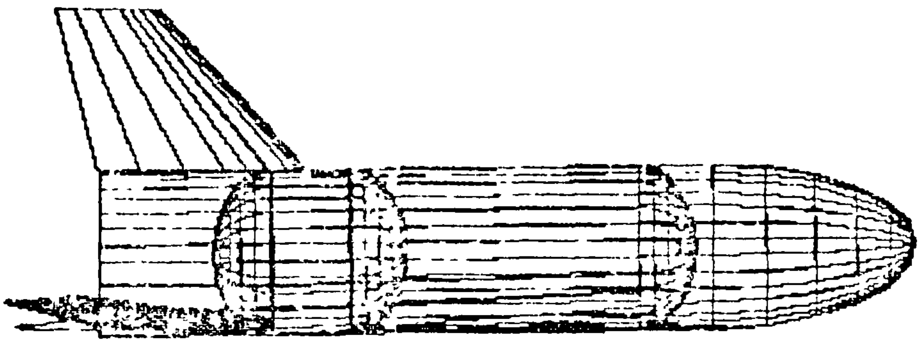


FIGURE 16A SECOND STAGE SIDE VIEW



FIGUPE 16B SECOND STAGE FRONTAL VIEW

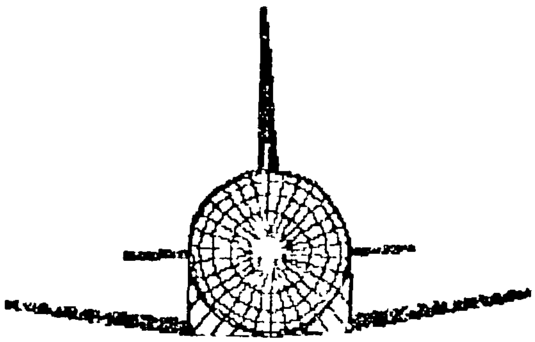


FIGURE 16C SECOND STAGE ORTHOGONAL VIEW

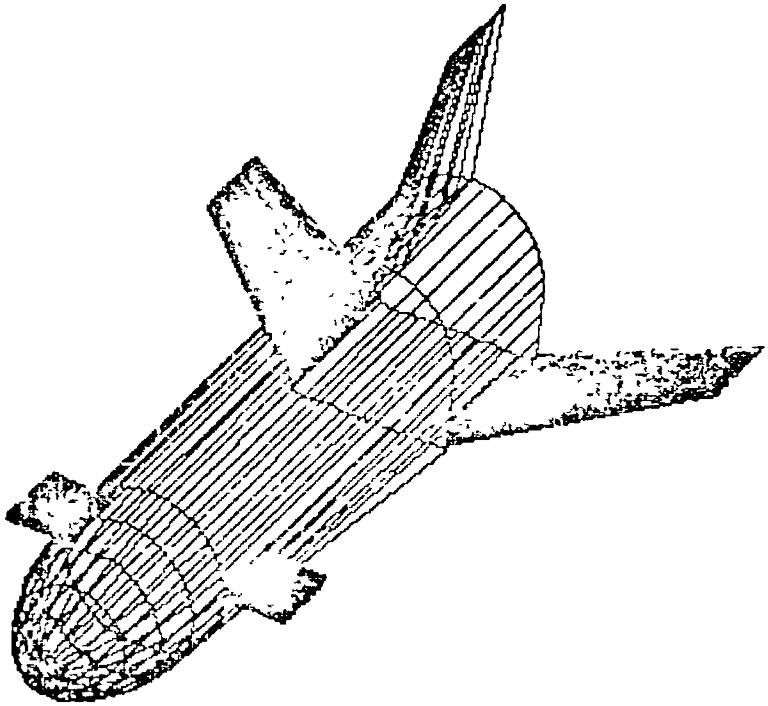


FIGURE 17. LAUNCH VEHICLE SECOND STAGE WEIGHT STATEMENT

WING GROUP		64253.	
TAIL GROUP		21051.	
CANARD	8537.		
VERTICAL	12454.		
BODY FLAP		8750.	
BODY GROUP		242338.	
NOSE (INC TPS)	43747.		
FWD SKIRT	19592.		
LOX TANK	27647.		
INTERTANK	0.		
FUEL TANK	99583.		
AFT SKIRT	0.		
THRUST STRUCTURE	30375.		
BASE SKIRT	21394.		
THERMAL PROTECTION		116237.	
BODY ENTRY TPS	54141.		
FLAME SHIELD	13035.		
LOX TANK INSULATION	0.		
INTERTANK INSULATION	3506.		
FUEL TANK INSULATION	6520.		
WING TPS	20136.		
CANARD TPS	6299.		
VERT TAIL TPS	9184.		
BODY FLAP TPS	54141.		
LANDING SYSTEM		29922.	
NOSE GEAR	2434.		
MAIN GEAR	27188.		
DROUGE CHUTE	0.		
ASCENT PROPULSION		125788.	
MAIN ENGINES	113656.		
ACCESSORIES	0.		
GIMBAL SYSTEM	8961.		
FUEL SYSTEM	1422.		
OXIDIZER SYSTEM	1749.		
AUX. PROP. SYS		5678.	
PRIME POWER		2104.	
ELECT CONV AND DISTR		1818.	
HYDRAULIC CONV AND DSTR		8640.	
AERO SURFACE CONTROLS		16101.	
WING SURFACE CONTROLS	10548.		
CANARD SURFACE CONTROLS	806.		
VERT TAIL SURFACE CONTROLS	2957.		
BODY FLAP CONTROLS	1789.		
AVIONICS		4900	
ENVIRONMENTAL CONTROL		0.	
PERSONNEL PROVISIONS		0.	
DRY WEIGHT			647578.
CONTINGENCY		64756.	

LAUNCH VEHICLE SECOND STAGE WEIGHT STATEMENT (CON'T)

BALLAST		0.	
EMPT, WEIGHT			712336.
RESIDUAL FLUIDS		15625.	
OXID PRESS GASSES	7223		
FUEL PRESS GASSES	2018.		
RCS	0.		
PRIME POWER	0.		
HYDRAULIC FLUIDS	6384.		
LANDING WEIGHT			727961.
MPS INFLIGHT LOSSES		71534.	
PRIME POWER PROPELLANT		377.	
RESERVES		0.	
ENTRY WEIGHT			799672.
RCS PROPELLANT		1311.	
FWD INTERSTAGE OR PAYLOAD ADAPTER		0.	
SEPERATION SYSTEM		0.	
STAGE INERT WEIGHT			801183.
MAINSTAGE PROPELLANT		5066640.	
IMPULSIVE PROPELLANT	5039251.		
FLIGHT PERFORMANCE RESERVES	27389.		
MAINSTAGE OXIDIZER	4342834.		
MAINSTAGE FUEL	723806.		
SEC STG LIFTOFF WEIGHT			5867823.
PRE-IGNITION PROPELLANT		22294.	
STAGE PRE-IGNITION WEIGHT			5890117.
SEC STG MASS FRACTION			.86346
TOTAL FUEL WEIGHT		748451.	
TOTAL LOX WEIGHT		4421258.	
ORBIT MANEUV PROP SYST			51390.
VEHICLE USEFUL PAYLOAD			1000000.

(*) ALL WEIGHTS ARE IN POUNDS

FIGURE 18. SECOND STG WEIGHTS AS A % OF EMPTY WEIGHT

ITEM	PCT
WING GROUP	9.020
TAIL GROUP	2.955
BODY FLAP	1.228
BODY GROUP	34.020
THERMAL PROTECTION	16.318
LANDING SYSTEM	4.200
ASCENT PROPULSION	17.659
AUX. PROPULSION SYSTEM	.797
PRIME POWER	.295
ELECT CONV AND DISTR	.255
HYDRAULIC CONV AND DISTR	1.213
AERO SURFACE CONTROLS	2.260
AVIONICS	.688
ENVIRONMENTAL CONTROL	.000
PERSONNEL PROVISIONS	.000
DRY WEIGHT	90.909
DESIGN RESERVE CONTINGENCY	9.091
BALLAST	.000
EMPTY WEIGHT	100.000

FIGURE 19. SECOND STAGE CG DATA

ITEM	AFT STA *	WEIGHT	X CG *
FORWARD NOSE1 STRUCTURE	62.50	43746.58	36.79
BALLAST	.00	.00	5.00
FORWARD SKIRT	85.18	19592.10	73.84
LOX TANK	216.49	27647.39	186.33
LOX TANK PRESSURANT	.00	7222.76	186.33
FUEL TANK	173.85	99582.64	126 56
FUEL TANK PRESSURANT	.00	2018.34	126.56
INTERTANK STRUCTURE	.00	.00	.00
LOX TANK INSULATION	.00	.00	186.33
FUEL TANK INSULATION	.00	6519.60	126.56
INTERTANK INSULATION	.00	3505.91	164.46
BASE SKIRT	250.19	21394.25	238.84
BODY FLAP	275.19	8750.00	262.69
TOTAL STAGE	250.19	638579.93	181.52

STAGE XCG (PCT LB) 72.554

(*) ALL STATIONS AND CENTERS OF GRAVITY ARE GIVEN IN
FEET LOCATED AFT OF STAGE NOSE

FIGURE 20 STATE HISTORIES

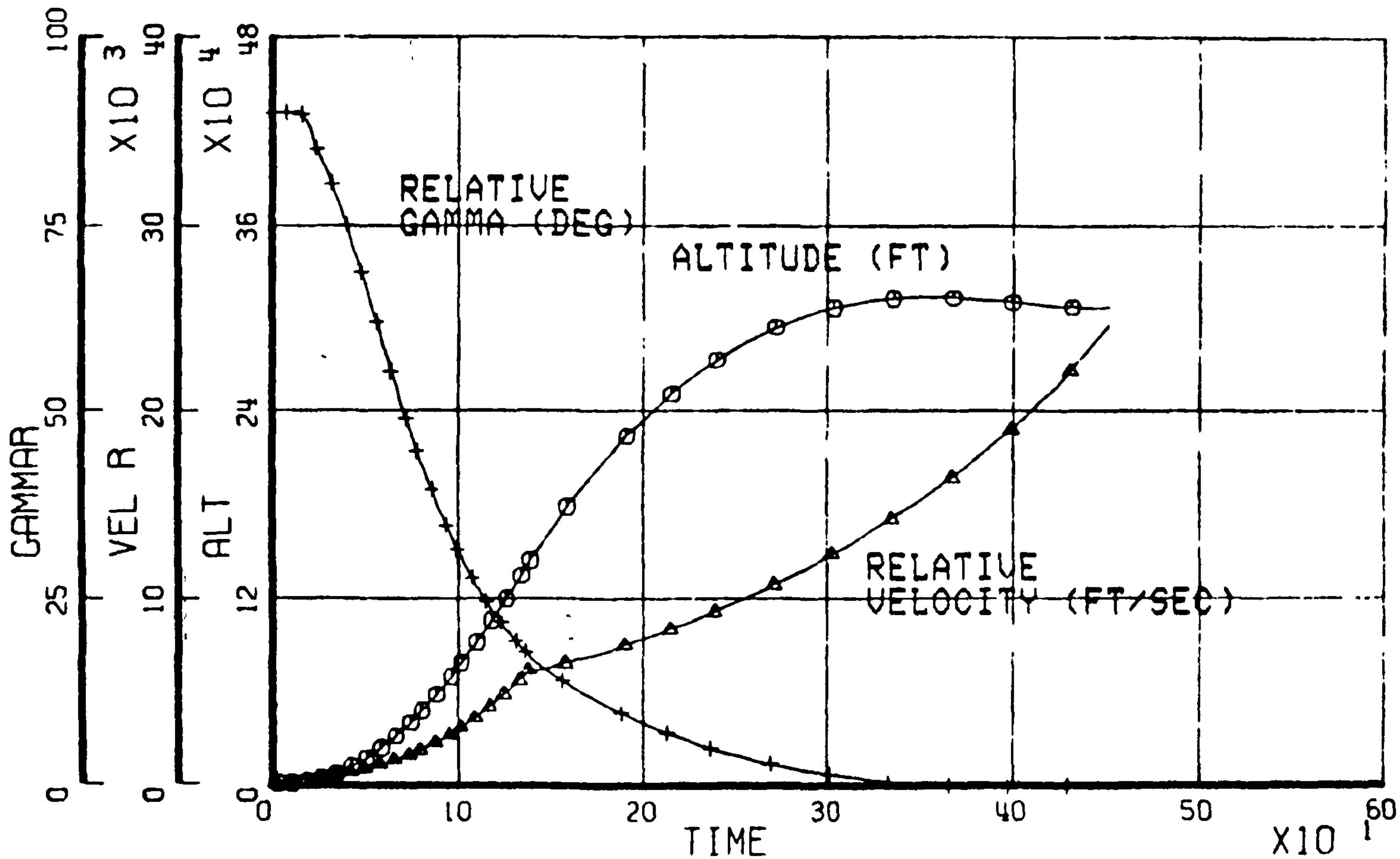


FIG 21 DYNAMIC PRESSURE VS TIME

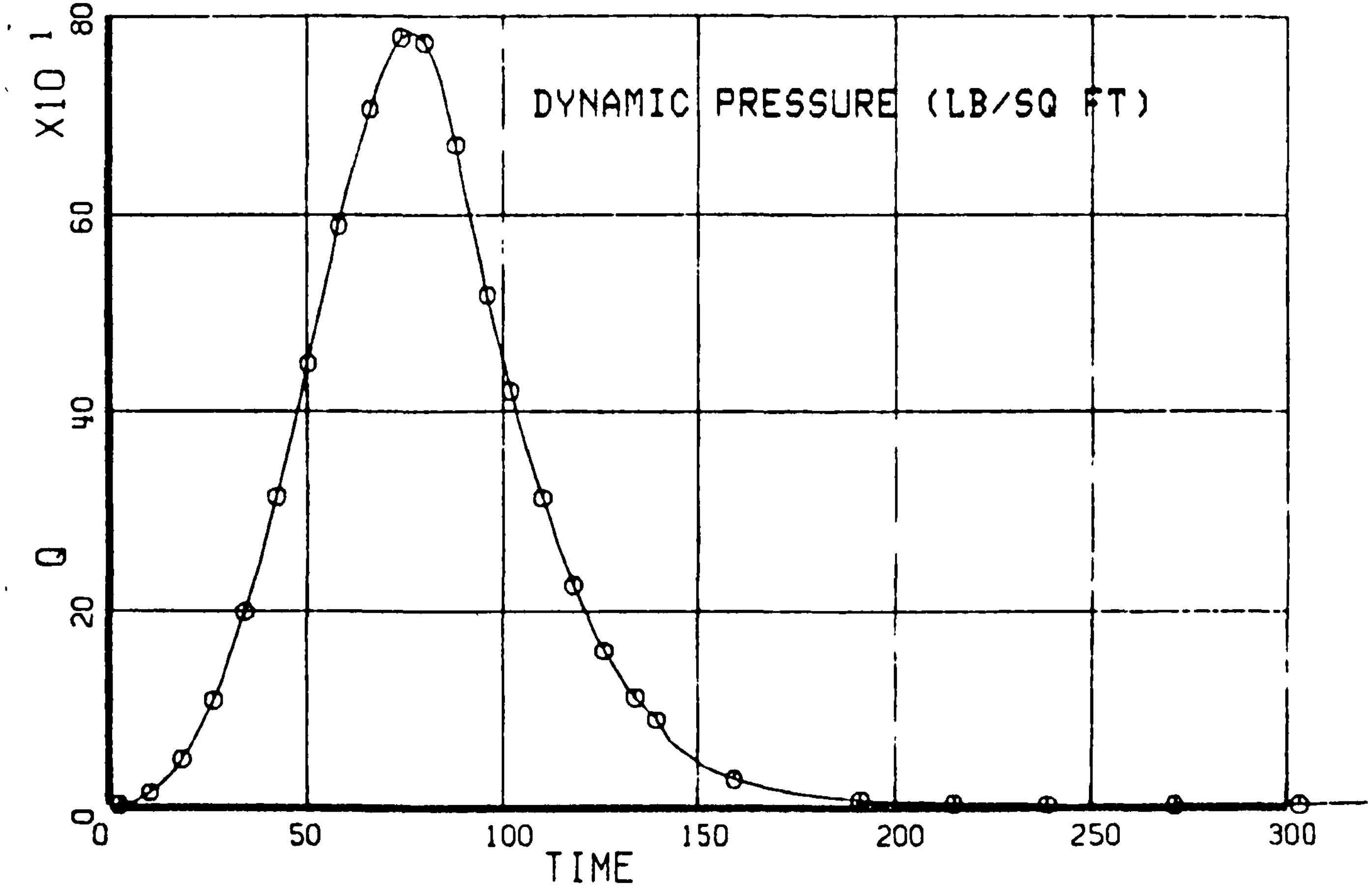
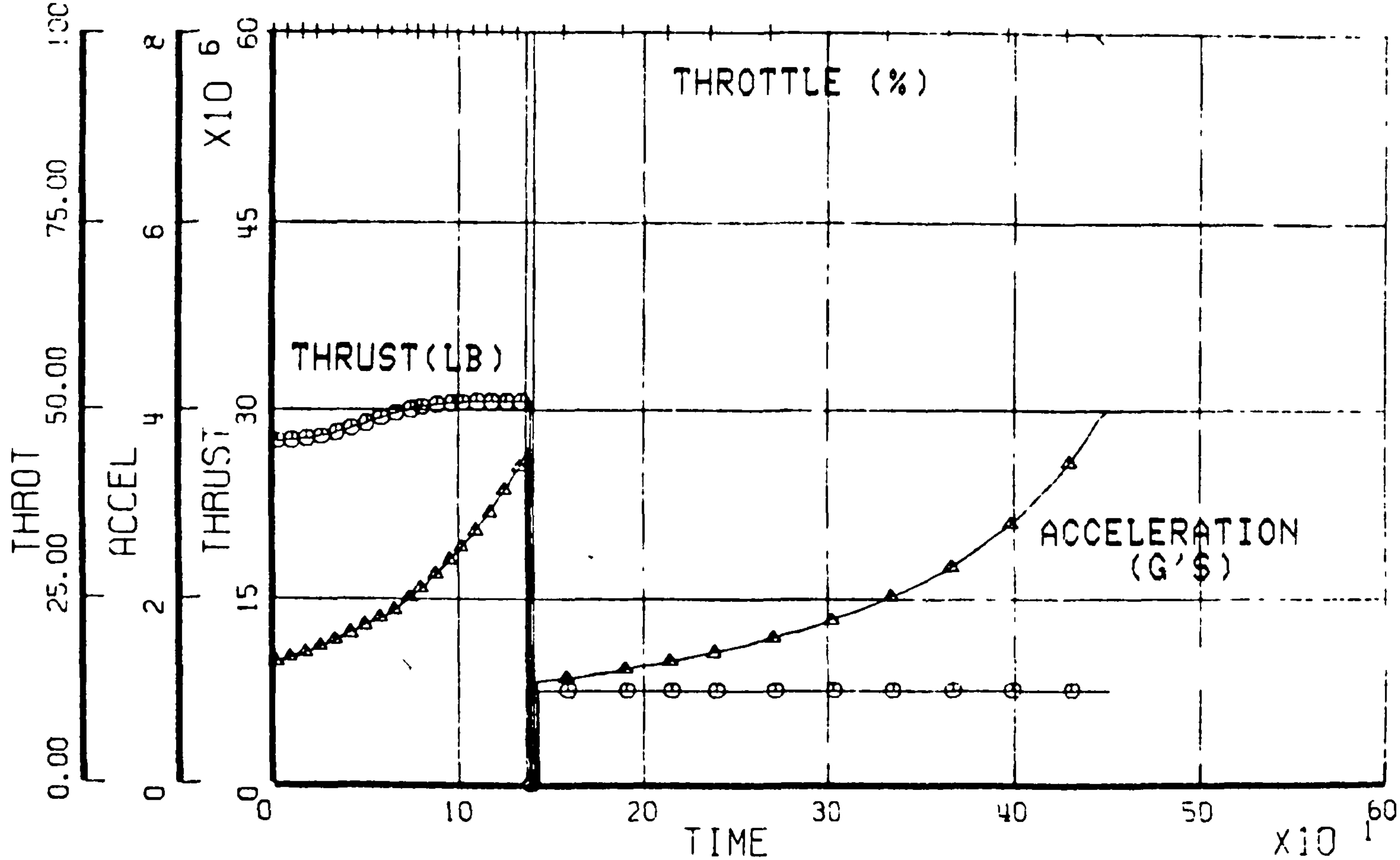


FIGURE 22 PROPULSION DATA



C-6

FIG 23 ALPHA, CHI P, FPA VS TIME

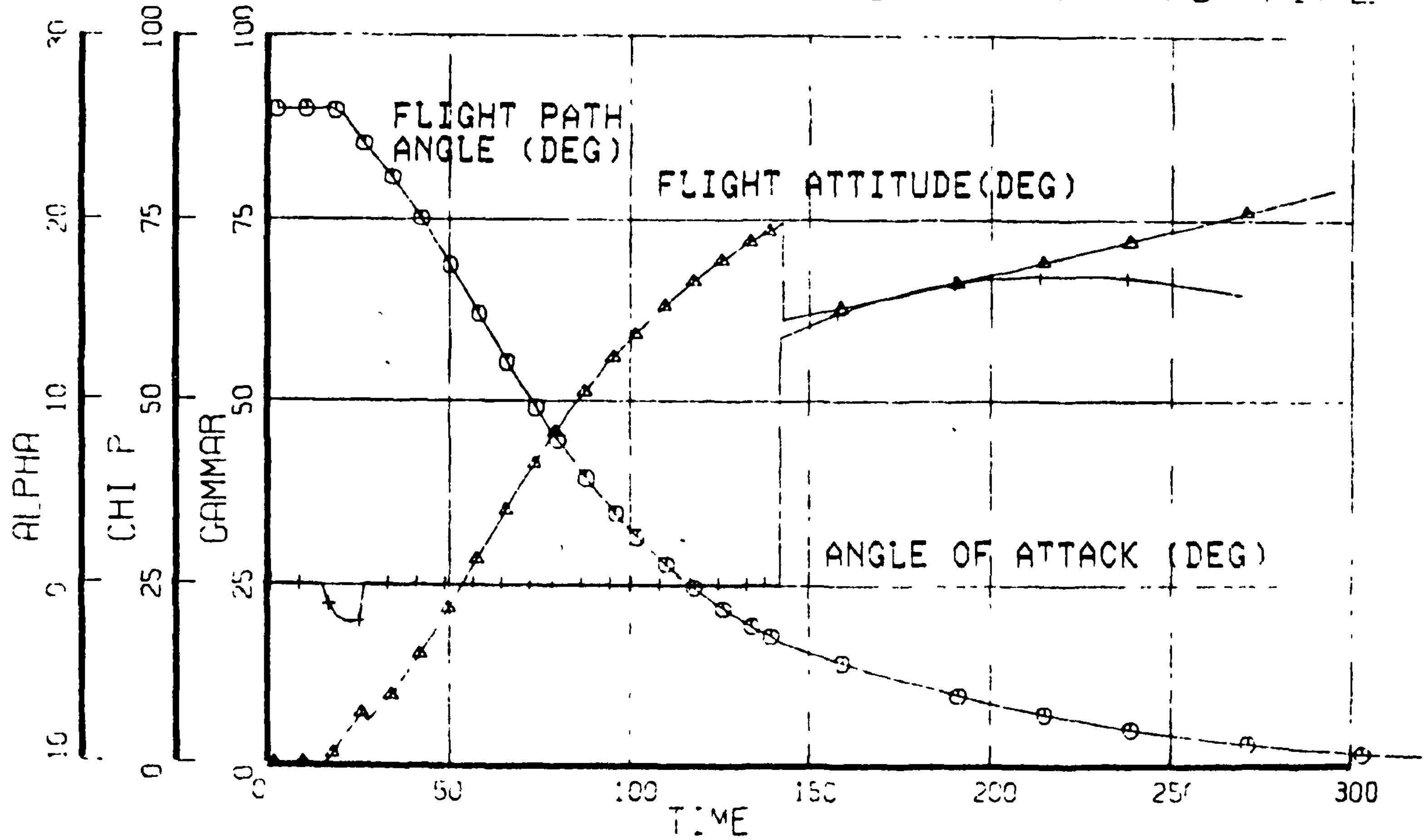
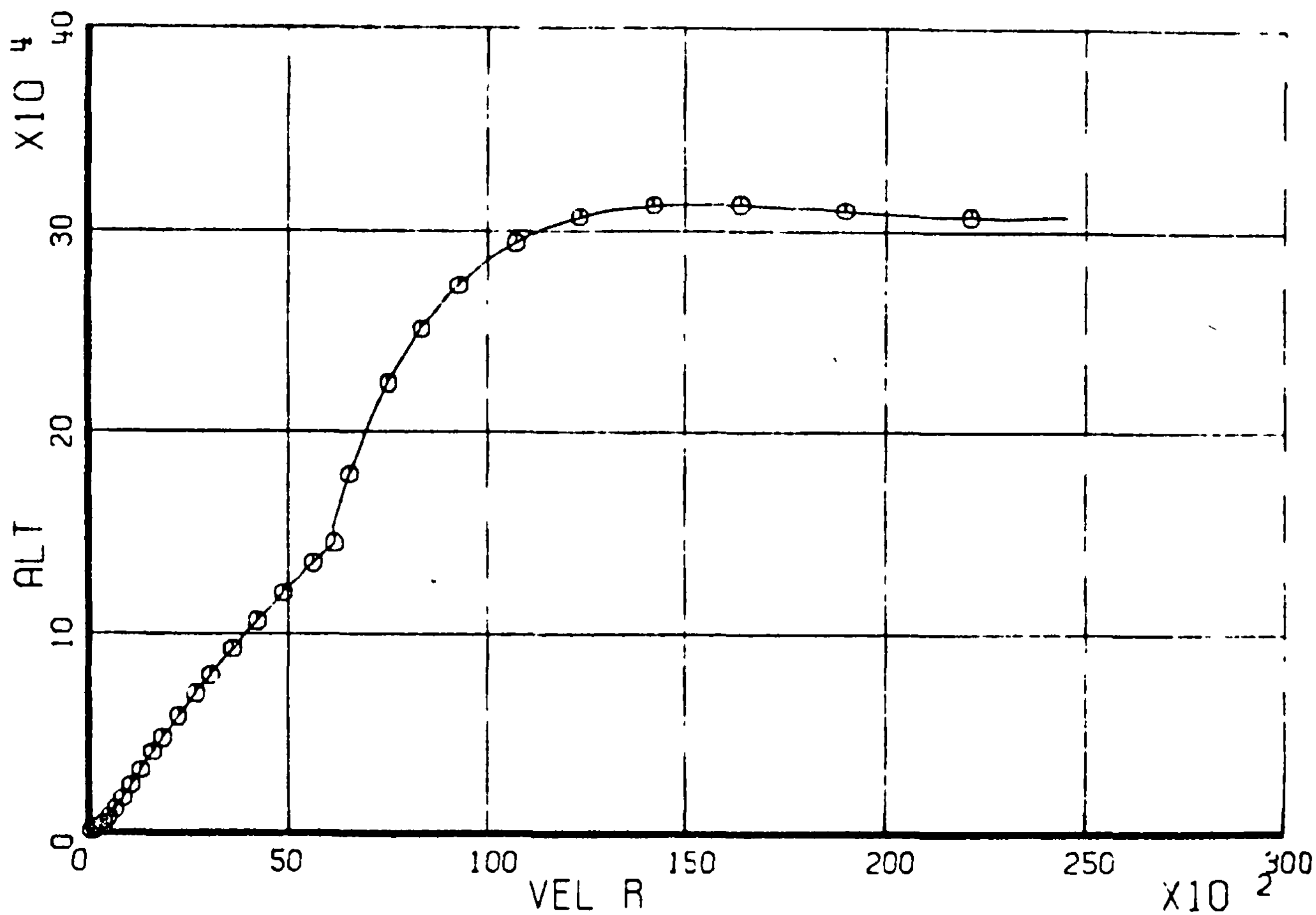


FIG 24 ALTITUDE VS REL VELOCITY



VEHILLE ASCENT DATA

FIGURE 25 ASCENT HEATING DATA Y

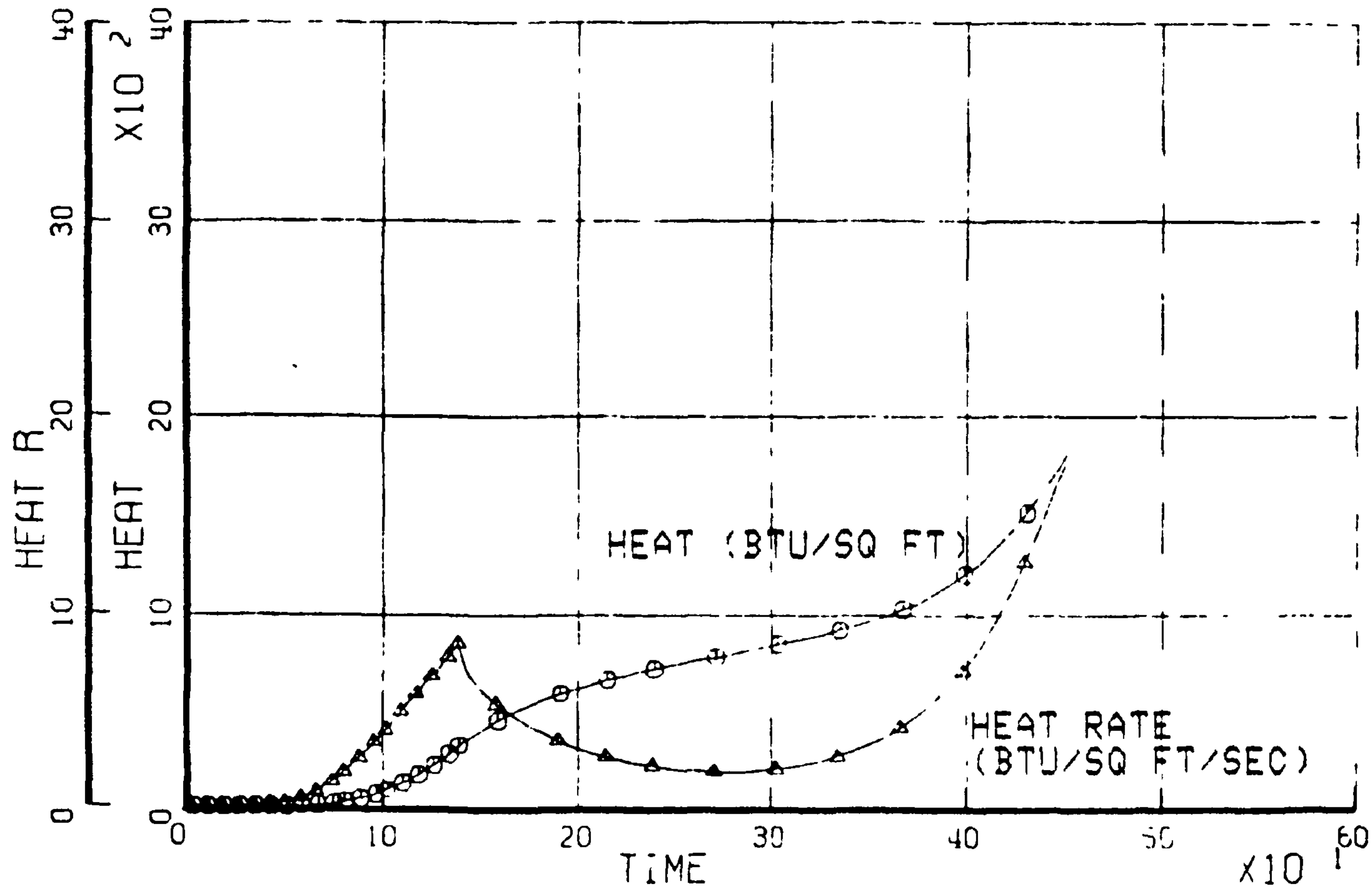
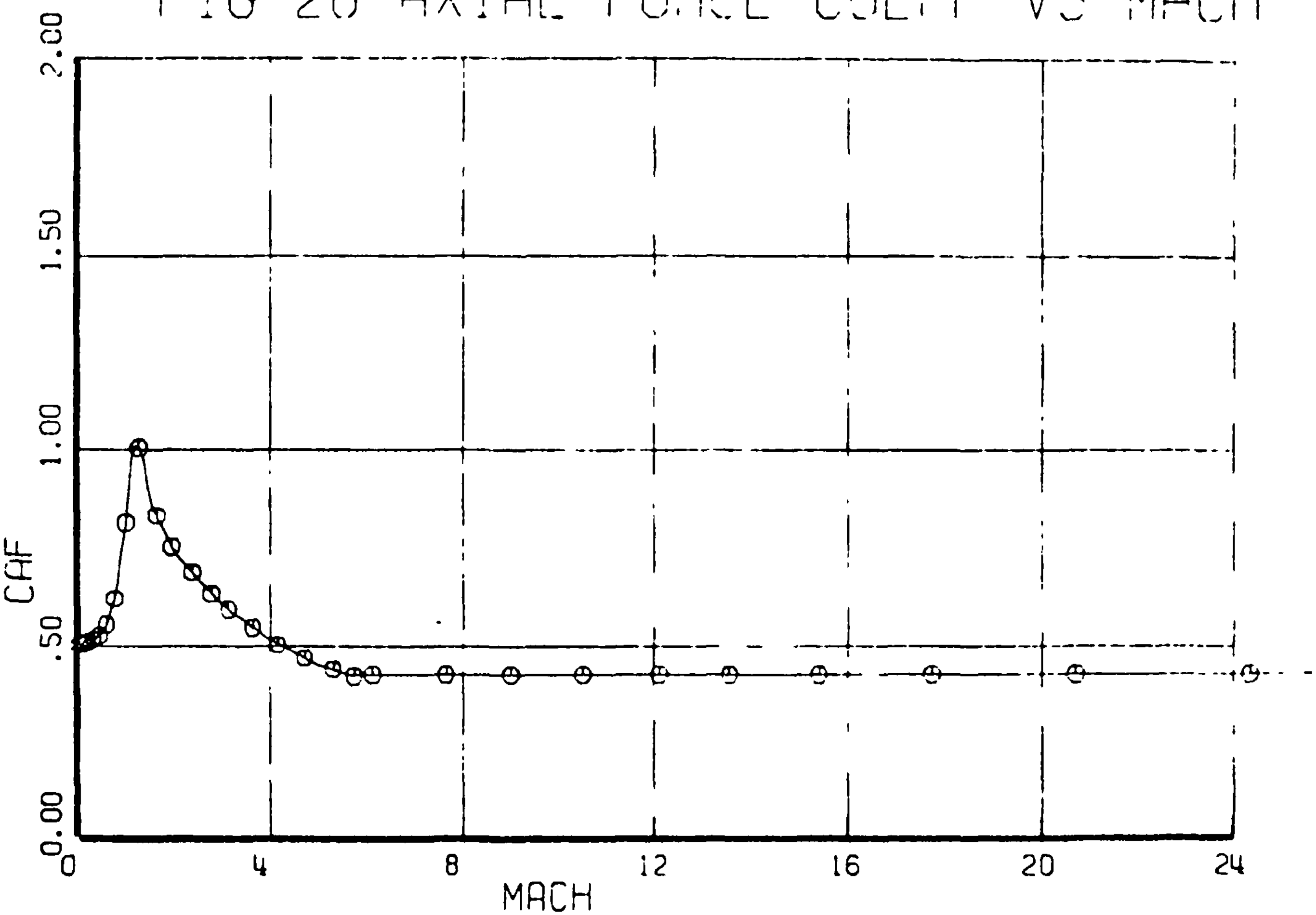


FIG 26 AXIAL FORCE COEFF VS MACH



VEHICLE ASCENT DATA

FIGURE 27 ALTITUDE VS BASE DRAG

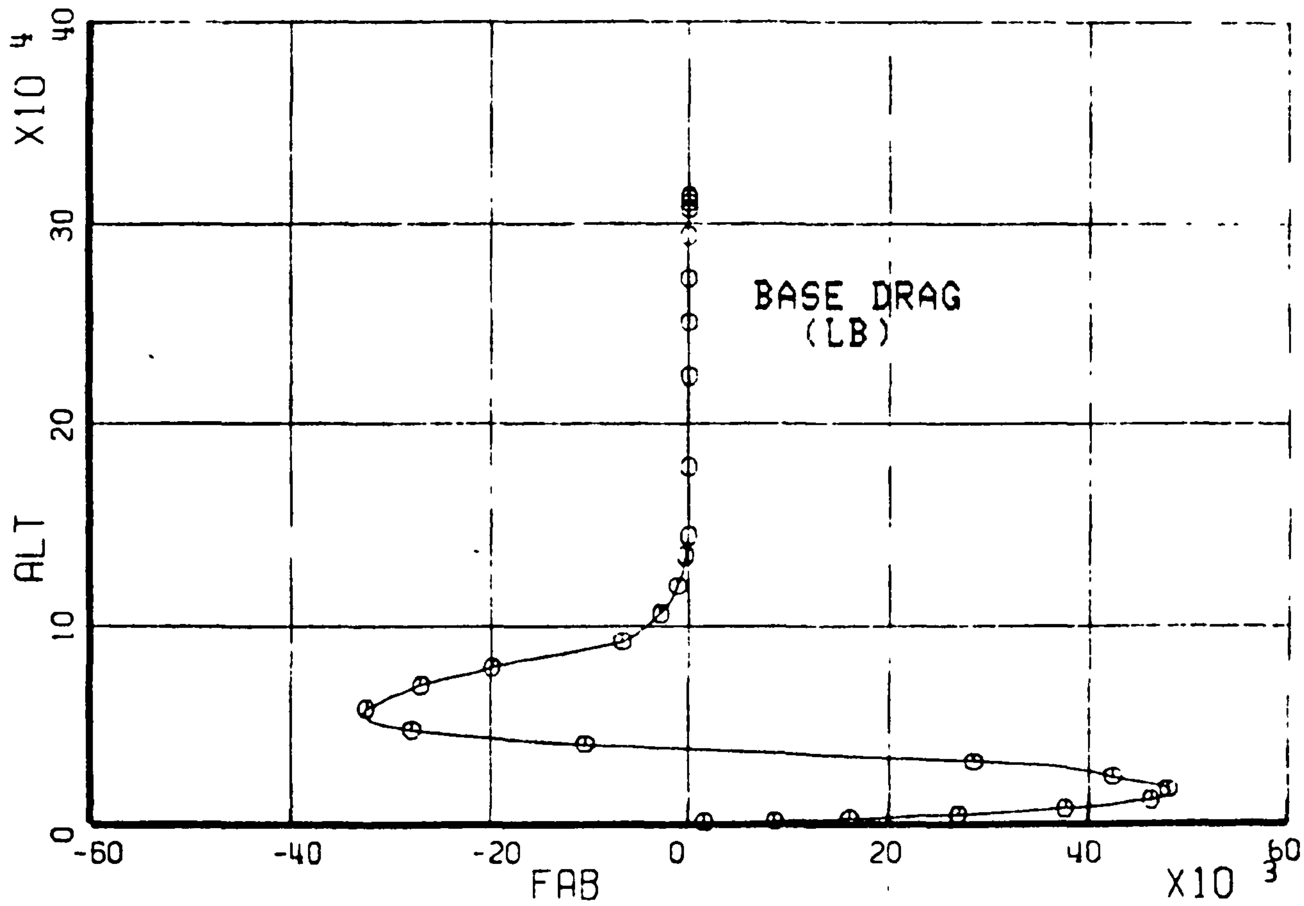


FIGURE 28 ALTITUDE VS RANGE G

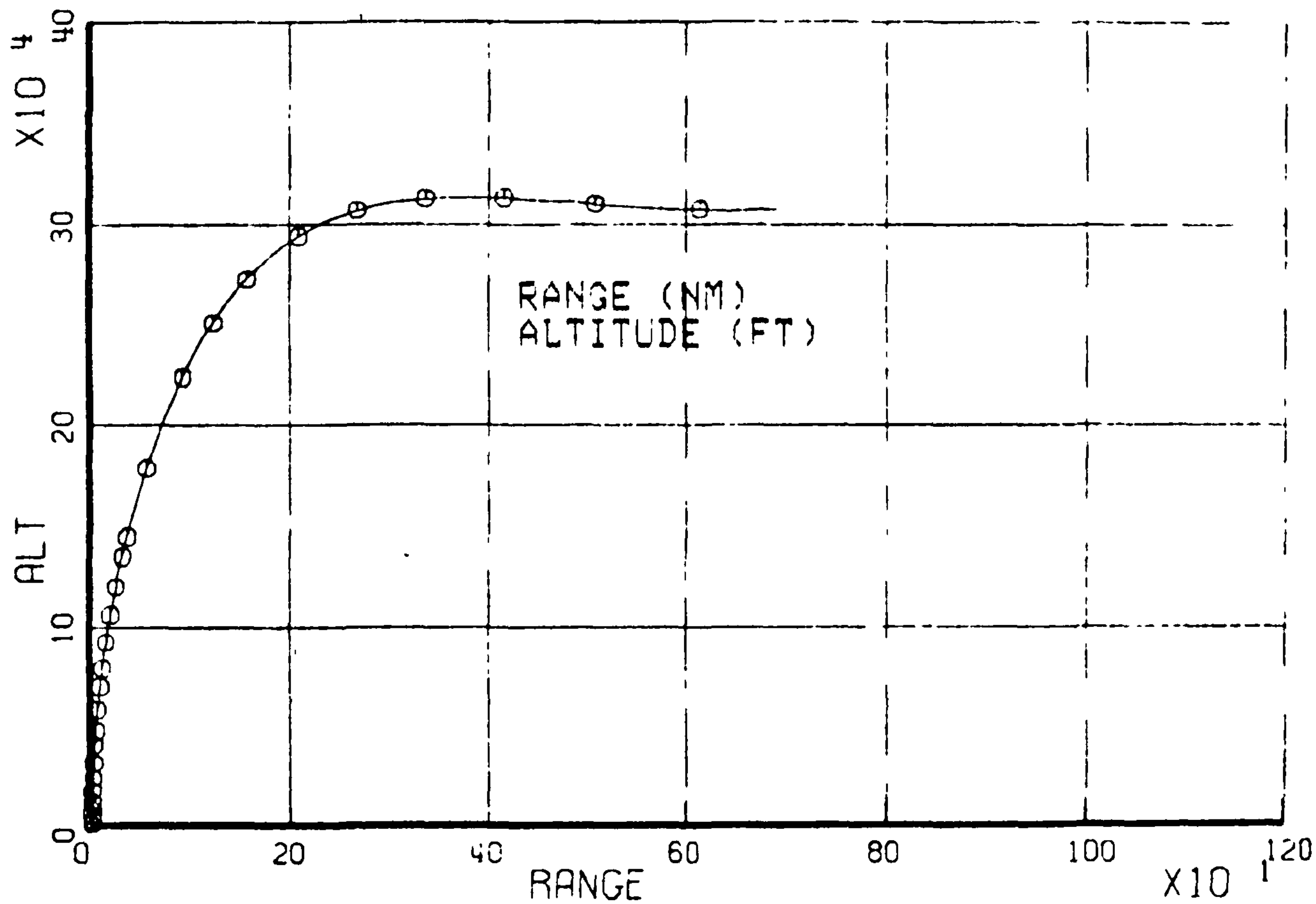


FIGURE 29 ASCENT TRAJECTORY

TIME (SEC)	THRUST (LBS)	WEIGHT (LBS)	ACCEL (G)	Q (PSF)	THROTL	CHIP (D/S)
(BEGIN LIFTOFF)						
0	27424231.5	21095563.0	1.300	.0	100 0	.00
2 0	27426012.2	20915206.0	1 311	.5	100 0	.01
4 0	27433181.7	20734849.0	1.323	1 9	100.0	.02
6 0	27444664.5	20554492.0	1.335	4.1	100.0	.02
8.0	27461056.0	20374135.0	1.347	8 1	100.0	.03
10 0	27482391.2	20193778 0	1.360	13 0	100 0	.04
12 0	27508771.2	20013421.0	1.373	19 [illegible]	100.0	.05
14.0	27540234.0	19833064.2	1.387	27 1	100.0	.06
(BEGIN TILT)						
16 0	27577004.5	19652707 2	1.401	36 4	100 0	.00
18 0	[illegible]18978.0	19472350.2	1.415	47.3	100.0	1.39
20 0	[illegible]	[illegible]	1.430	59.[illegible]	100.0	2.78
22 0	27718[illegible]61 2	19111636 2	1.445	74.1	100 0	4.17
24 0	27776267.7	18931279.2	1.461	90.1	100.0	5.56
26 0	27838870 7	18750922 5	1.477	107.9	100.0	6.95
(END TILT)						
28 0	27906404 0	18570565 5	1.494	127.6	100.0	5.99
30 0	27972664.2	18390208.5	1.511	149 1	100 0	7 08
32 0	28055513.7	18209851.5	1.529	172.4	100.0	8.26
34 0	28136632.5	18029494 5	1 547	197.4	100 0	9.51
36.0	28221744.5	17849137.5	1.566	224.1	100.0	10.84
38.0	28310499 0	17668780 7	1.585	252.4	100.0	12.24
40.0	28403517.7	17488423.7	1.604	282 2	100.0	13.70
42.0	28497377.5	17308066.7	1.624	313.4	100.0	15.21
44.0	28594659 5	17127709.7	1.644	345.7	100 0	16.76
46 0	28693832.5	16947352 7	1.665	379.1	100.0	18.36
48.0	28794464 0	16766995.9	1 685	413.3	100 0	19.98
50 0	28896026.2	16586639.0	1 706	448.2	100 0	21.63
52.0	28998004.0	16406222.0	1.726	483.3	100 0	23.30
54.0	29099897.0	16225925 0	1 746	518.5	100.0	24.98
56.0	29201192.7	16045568.1	1.766	553.2	100 0	26.67
58.0	29301360.0	15865211.1	1.785	587.3	100.0	28.35
60.0	29399952.0	15684854 1	1.802	620.1	100.0	30.03
62.0	29496454.5	15504497.2	1.817	651.1	100.0	31.71
64 0	29590403.5	15324140.2	1 841	679.9	100.0	33.37
66.0	29681377.7	15143783 2	1.866	706.3	100.0	35.01
68.0	29769015.7	14963426 4	1.895	729.9	100.0	36.63
70.0	29852946.5	14783069.4	1.928	750.2	100.0	38.23
72.0	29933035.2	14602712.4	1.962	767.1	100 0	39.80
74.0	30008624.7	14422355.5	1.993	778 3	100 0	41.34
76.0	30079498.5	14241998.5	2.026	783.5	100.0	42.85
(MAXIMUM DYNAMIC PRESSURE)						
78.0	30145413.5	14061641.5	2.061	782.0	100.0	44.32
80.0	30206204.5	13881284.6	2.096	773.2	100.0	45.76
80.0	30206204.5	13881284.6	2.096	773.2	100.0	45.76
82.0	30261773.5	13700927.6	2.132	757.2	100.0	47.16
84.0	30312110.0	13520570 6	2.168	734.2	100.0	48.53
86.0	30357251.0	13340213.6	2.206	704.8	100 0	49.85

VEHICLE ASCENT TRAJECTORY

TIME	THRUST	WEIGHT	ACCEL	Q	THROTL	CHIP
88.0	30397320.2	13159856.7	2.244	670.2	100.0	51.14
90.0	30432154.0	12979499.7	2.283	628.4	100.0	52.39
92.0	30462743.2	12799142.7	2.323	590.7	100.0	53.61
94.0	30489459.5	12618785.9	2.363	553.9	100.0	54.79
96.0	30512730.5	12438428.9	2.404	518.3	100.0	55.93
98.0	30532960.5	12258071.9	2.445	484.1	100.0	57.03
100.0	30550509.7	12077715.0	2.487	451.5	100.0	58.10
100.0	30550509.7	12077715.0	2.487	451.5	100.0	58.10
102.0	30565707.0	11897358.0	2.530	420.4	100.0	59.14
104.0	30578852.2	11717001.0	2.573	391.1	100.0	60.14
106.0	30590212.2	11536644.0	2.618	363.3	100.0	61.11
108.0	30600025.7	11356287.1	2.663	337.1	100.0	62.05
110.0	30608506.7	11175930.1	2.709	312.4	100.0	62.96
112.0	30615847.7	10995573.1	2.757	288.4	100.0	63.84
114.0	30622160.0	10815216.2	2.807	265.6	100.0	64.69
116.0	30627583.2	10634859.2	2.857	244.4	100.0	65.51
118.0	30632240.5	10454502.2	2.909	224.5	100.0	66.30
120.0	30636238.7	10274145.4	2.963	206.1	100.0	67.07
122.0	30639670.2	10093788.4	3.018	189.0	100.0	67.82
124.0	30642613.7	9913431.4	3.075	173.2	100.0	68.54
126.0	30645138.2	9733074.5	3.134	158.6	100.0	69.23
128.0	30647303.5	9552717.5	3.195	145.2	100.0	69.91
130.0	30649160.2	9372360.5	3.256	132.9	100.0	70.56
132.0	30650752.7	9192003.6	3.323	121.6	100.0	71.19
134.0	30652119.5	9011646.6	3.391	111.3	100.0	71.80
136.0	30653292.7	8831289.6	3.461	101.9	100.0	72.40
138.0	30654301.5	8650932.7	3.534	93.3	100.0	72.97
139.3	30654861.5	8537652.1	3.522	88.4	100.0	73.32
(END BOOSTER STAGE BURN)						
139.3	.0	6941452.9	.011	88.4	.0	73.32
143.3	.0	6941452.9	.008	64.9	.0	74.43
(BEGIN SECOND STAGE BURN)						
143.3	7614940.6	6919170.2	1.101	64.9	100.1	61.03
151.3	7612653.2	6788441.6	1.121	41.0	100.0	61.87
159.3	7613555.6	6657713.1	1.144	27.3	100.0	62.72
167.3	7614093.3	6526984.4	1.167	18.6	100.0	63.59
175.3	7614417.7	6396255.9	1.190	12.8	100.0	64.46
183.3	7614615.0	6265527.2	1.215	8.9	100.0	65.35
191.3	7614735.9	6134798.7	1.241	6.3	100.0	66.26
191.3	7614940.6	6134798.7	1.241	6.3	100.0	66.26
199.3	7614810.5	6004070.1	1.268	4.5	100.0	67.17
207.3	7614856.8	5873341.5	1.297	3.2	100.0	68.10
215.3	7614885.8	5742612.9	1.326	2.3	100.0	69.04
223.3	7614904.1	5611884.3	1.357	1.7	100.0	69.99
231.3	7614915.9	5481155.7	1.389	1.3	100.0	70.96
239.3	7614923.4	5350427.1	1.423	1.0	100.0	71.93
239.3	7614940.6	5350427.1	1.423	1.0	100.0	71.93
247.3	7614928.4	5219698.5	1.459	.8	100.0	72.92
255.3	7614931.6	5088969.9	1.496	.6	100.0	73.92
263.3	7614933.8	4958241.3	1.536	.5	100.0	74.92
271.3	7614935.3	4827512.7	1.577	.4	100.0	75.94
279.3	7614936.4	4696784.1	1.621	.3	100.0	76.97

VEHICLE ASCENT TRAJECTORY

TIME	THRUST	WEIGHT	ACCEL	Q	THROTL	CHIP
287.3	7614937.1	4566055.6	1.668	.3	100.0	78.00
295.3	7614937.6	4435326.9	1.717	.3	100.0	79.04
303.3	7614938.0	4304596.4	1.769	.3	100.0	80.09
311.3	7614938.2	4173869.8	1.824	.2	100.0	81.15
319.3	7614938.4	4043141.2	1.889	.2	100.0	82.21
327.3	7614938.6	3912412.6	1.946	.2	100.0	83.28
335.3	7614938.7	3781684.0	2.014	.2	100.0	84.35
343.3	7614938.7	3650955.4	2.086	.2	100.0	85.43
351.3	7614938.7	3520226.8	2.163	.3	100.0	86.51
359.3	7614938.7	3389498.2	2.247	.3	100.0	87.59
367.3	7614938.7	3258769.6	2.337	.3	100.0	88.68
375.3	7614938.7	3128041.0	2.434	.3	100.0	89.76
383.3	7614938.6	2997312.4	2.541	.4	100.0	90.85
391.3	7614938.5	2866583.8	2.656	.4	100.0	91.93
399.3	7614938.4	2735855.2	2.783	.5	100.0	93.02
407.3	7614938.3	2605126.7	2.923	.6	100.0	94.10
415.3	7614938.2	2474398.1	3.077	.6	100.0	95.18
423.3	7614938.1	2343669.5	3.249	.7	100.0	96.25
431.3	7614938.1	2212940.9	3.441	.8	100.0	97.32
439.3	7614938.0	2082212.3	3.657	.9	100.0	98.39
447.3	7614938.0	1951483.7	3.90[illegible]	.9	100.0	99.45
(INJECTION)						
451.6	7519675.0	1879318.7	4.000	1.0	98.7	100.02

FIGURE 29 ASCENT TRAJECTORY

TIME (SEC)	VEL REL (FPS)	VEL I (FPS)	GAMMA R (DEG)	GAMMA I (DEG)	ALTITUDE (FT)	RANGE (NM)
(BEGIN LIFTOFF)						
.0	.0	1519.0	31.82	.00	-.5	.0
2.0	19.9	1519.1	89.91	.75	19.0	.0
4.0	40.6	1519.5	89.91	1.53	79.5	.0
6.0	62.0	1520.2	89.91	2.34	181.7	.0
8.0	84.2	1521.3	89.90	3.17	328.5	.0
10.0	107.3	1522.7	89.90	4.04	519.7	.0
12.0	131.1	1524.5	89.90	4.93	758.0	.0
14.0	155.8	1526.8	89.90	5.86	1044.2	.0
(BEGIN TILT)						
16.0	181.4	1529.6	90.11	6.81	1381.7	.0
18.0	208.0	1534.0	89.79	7.79	1771.0	.0
20.0	235.4	1541.0	89.06	8.79	2214.2	.0
22.0	263.8	1551.0	87.99	9.79	2713.2	.0
24.0	293.3	1563.8	86.69	10.79	3269.7	.0
26.0	323.9	1579.5	85.22	11.79	3885.0	.0
(END TILT)						
28.0	355.7	1595.4	84.13	12.81	4561.5	.0
30.0	388.7	1613.2	83.04	13.84	5301.0	.0
32.0	423.1	1633.8	81.88	14.85	6105.5	.1
34.0	458.8	1657.2	80.63	15.85	6976.7	.1
36.0	495.9	1683.6	79.31	16.82	7916.5	.1
38.0	534.5	1713.1	77.92	17.76	8926.2	.1
40.0	574.7	1745.9	76.47	18.66	10007.5	.2
42.0	616.5	1782.0	74.97	19.52	11161.5	.2
44.0	660.1	1821.5	73.43	20.32	12389.7	.3
46.0	705.5	1864.5	71.84	21.07	13692.5	.4
48.0	752.7	1910.9	70.22	21.76	15071.2	.4
50.0	802.0	1960.7	68.58	22.38	16526.2	.5
52.0	853.2	2013.9	66.93	22.94	18057.7	.6
54.0	906.5	2070.5	65.26	23.43	19666.0	.7
56.0	961.8	2130.3	63.58	23.85	21350.7	.9
58.0	1019.2	2193.4	61.91	24.20	23111.0	1.0
60.0	1078.7	2259.5	60.24	24.48	24946.7	1.2
62.0	1140.2	2328.4	58.57	24.70	26856.2	1.4
64.0	1203.8	2400.2	56.93	24.85	28838.0	1.6
66.0	1270.0	2475.2	55.30	24.95	30890.7	1.8
68.0	1339.0	2553.4	53.69	25.00	33014.0	2.1
70.0	1411.0	2635.0	52.10	25.00	35206.5	2.3
72.0	1486.3	2720.1	50.55	24.95	37467.5	2.6
74.0	1564.8	2808.6	49.02	24.87	39790.5	2.9
76.0	1646.5	2900.3	47.53	24.75	42192.5	3.3
(MAXIMUM DYNAMIC PRESSURE)						
78.0	1731.5	2995.4	46.07	24.60	44654.0	3.7
80.0	1819.8	3093.8	44.64	24.41	47179.7	4.1
80.0	1819.8	3093.8	44.64	24.41	47179.7	4.1
82.0	1911.6	3195.6	43.26	24.20	49768.2	4.5
84.0	2006.8	3300.7	41.91	23.96	52418.7	5.0
86.0	2105.5	3409.1	40.60	23.70	55129.2	5.5

TIME	VEL REL	VEL I	GAMM R	GAMM I	ALTITUDE	RANGE
88.0	2207.8	3520.9	39.32	23.41	57835.7	6.1
90.0	2313.6	3636.1	38.09	23.11	60725.2	6.6
92.0	2423.0	3754.6	36.89	22.79	63607.2	7.3
94.0	2536.0	3876.5	35.74	22.46	66542.2	7.9
96.0	2652.7	4001.7	34.61	22.12	69531.0	8.6
98.0	2773.1	4130.4	33.53	21.77	72569.7	9.3
100.0	2897.1	4262.4	32.48	21.41	75657.5	10.1
100.0	2897.1	4262.4	32.48	21.41	75657.5	10.1
102.0	3024.6	4397.9	31.47	21.04	78792.2	10.9
104.0	3156.3	4536.8	30.49	20.67	81973.7	11.8
106.0	3291.5	4679.2	29.54	20.29	85197.0	12.7
108.0	3430.5	4825.1	28.63	19.91	88463.2	13.7
110.0	3573.4	4974.5	27.74	19.54	91770.5	14.7
112.0	3720.1	5127.6	26.89	19.16	95116.5	15.8
114.0	3870.9	5284.4	26.07	18.78	98500.2	16.9
116.0	4025.5	5444.9	25.27	18.40	101920.0	18.0
118.0	4184.4	5609.3	24.51	18.02	105374.2	19.3
120.0	4347.3	5777.6	23.77	17.65	108861.7	20.5
122.0	4514.6	5949.8	23.05	17.29	112382.0	21.9
124.0	4686.1	6126.2	22.36	16.92	115935.0	23.3
126.0	4862.1	6306.8	21.70	16.56	119512.7	24.7
128.0	5042.6	6491.7	21.06	16.21	123131.0	26.2
130.0	5227.8	6681.0	20.44	15.86	126766.0	27.8
132.0	5417.7	6874.9	19.85	15.52	130420.2	29.4
134.0	5612.5	7073.5	19.27	15.18	134113.0	31.1
136.0	5812.4	7277.0	18.72	14.85	137916.2	32.9
138.0	6017.4	7485.5	18.18	14.53	141559.2	34.7
139.3	6148.9	7619.1	17.86	14.33	143913.2	35.9
(END BOOSTER STAGE BURN)						
139.3	6148.9	7619.1	17.86	14.33	143943.2	35.9
143.3	6110.1	7587.5	16.83	13.49	151252.2	39.7
(BEGIN SECOND STAGE BURN)						
143.3	6110.1	7587.5	16.83	13.49	151252.2	39.7
151.3	6317.7	7804.2	15.42	12.43	165143.5	47.5
159.3	6535.8	8030.2	14.09	11.43	178124.7	55.6
167.3	6764.2	8265.6	12.85	10.49	190507.5	64.1
175.3	7002.9	8510.4	11.70	9.60	202304.2	72.9
183.3	7252.0	8764.7	10.62	8.77	213527.2	82.0
191.3	7511.3	9028.6	9.61	7.99	223553.0	91.4
191.3	7511.6	9028.9	9.61	7.99	223592.7	91.4
199.3	7781.3	9302.5	8.68	7.25	233305.2	101.3
207.3	8061.5	9586.1	7.81	6.56	242380.2	111.5
215.3	8352.2	9879.7	7.00	5.91	250831.0	122.1
223.3	8653.7	10183.7	6.25	5.31	258671.2	133.1
231.3	8965.2	10498.3	5.56	4.74	265911.5	144.5
239.3	9289.9	10823.8	4.92	4.22	272567.2	156.3
239.3	9289.9	10823.8	4.92	4.22	272567.5	156.3
247.3	9625.2	11160.5	4.32	3.73	278651.7	168.5
255.3	9972.2	11508.9	3.78	3.27	284173.7	181.2
263.3	10331.5	11869.2	3.27	2.85	289153.7	194.4
271.3	10703.4	12242.0	2.81	2.46	293620.7	208.0
279.3	11088.4	12627.8	2.39	2.10	297567.2	222.1

VEHICLE ASCENT TRAJECTORY

TIME	VEL REL	VEL I	GAMM R	GAMM I	ALTITUDE	RANGE
287.3	11487.0	13027 0	2.00	1.77	301019.5	236.0
295.3	11899.9	13440.4	1.65	1.46	303994.5	252 0
303.3	12327.7	13868.6	1.33	1.19	306511.2	267.7
311.3	12771.1	14312.2	1.05	.93	308590.5	283.9
319.3	13230.9	14772.2	.79	.71	310253.0	300.8
327.3	13708.0	15249.5	.56	.51	311520.7	318.3
335.3	14203.4	15745.0	.36	.33	312419.0	336.4
343.3	14718.1	16259.8	.19	.17	312974.2	355.1
351.3	15253.5	16795.2	.04	.04	313214.7	374.6
359.3	15810.6	17352.5	-.08	-.07	313172.0	394.7
367.3	16391.7	17933.4	-.18	-.16	312880.2	415 6
375.3	16997.9	18539.5	-.25	-.23	312376.2	437.3
383.3	17631.2	19172.8	-.30	-.28	311701 5	459 7
391.3	18294.1	19835 6	-.33	-.31	310900.2	483.0
399.3	18989.0	20530.4	-.34	-.31	310023 7	507.2
407.3	19718.9	21260.3	-.32	-.30	309126.0	532.3
415.3	20487.3	22028.6	-.28	-.26	308270.0	558.4
423.3	21298.1	22839.3	-.22	-.21	307523.3	585.5
431.3	22155.9	23697.1	-.14	-.13	306963.5	613.7
439.3	23066.5	24607.6	-.04	-.03	306677.0	643 0
447.3	24036.3	25577.5	.09	.09	306761.7	673.6
(INJECTION)						
451.6	24595.2	26136.4	.17	.16	307005.2	690.9

FIGURE 29 ASCENT TRAJECTORY

TIME (SEC)	MACH	ALPHA (DEG)	LAT (DEG)	LONG (DEG)	HT RT (B/SF/S)	TOT HT (B/SF)	REL AZ (DEG)
(BEGIN LIFTOFF)							
.0	.00	.000	5.46	-80.60	.0	.0	90.0
2.0	.02	-.008	5.46	-80.60	.0	.0	90.0
4.0	.04	-.016	5.46	-80 60	.0	.0	90.0
6.0	.05	-.025	5.46	-80.60	.0	.0	90.0
8.0	.07	-.033	5.46	-80.60	.0	.0	90.0
10.0	.09	-.040	5.46	-80.60	.0	.0	90.0
12.0	.12	-.049	5.46	-80.60	.0	.0	90.0
14.0	.14	-.056	5.46	-80.60	.0	.0	90.0
(BEGIN TILT)							
16.0	.16	-.002	5.46	-80.60	.0	.0	90.0
18.0	.18	-1.118	5.46	-80.60	.0	.0	90.0
20.0	.21	-1.758	5.46	-80 60	.0	.0	90.0
22.0	.23	-2.068	5.46	-80 60	.0	.0	90.0
24.0	.26	-2.147	5.46	-80.60	.0	.1	90.0
26.0	.29	-2.061	5.46	-80.60	.0	.1	90.0
(END TILT)							
28 0	.32	.000	5.46	-80.60	.0	.1	90.0
30.0	.35	.000	5.46	-80.60	0	.2	90.0
32.0	.38	.000	5.46	-80.60	.0	.2	90.0
34.0	.41	.000	5.46	-80.60	.0	.3	90.0
36.0	.45	.000	5.46	-80.60	.1	.4	90.0
38.0	.48	.000	5.46	-80.60	.1	.6	90.0
40.0	.52	.000	5.46	-80.60	.1	.7	90.0
42.0	.56	.000	5.46	-80.60	.1	.9	90.0
44.0	.60	.000	5.46	-80.60	.1	1.2	90.0
46.0	.65	.000	5.46	-80.60	.2	1.5	90.0
48.0	.69	.000	5.46	-80.60	.2	1.9	90.0
50.0	.74	.000	5.46	-80.60	.2	2.3	90.0
52.0	.80	.000	5.46	-80.59	.3	2.8	90.0
54.0	.85	.000	5.46	-80.59	.3	3.4	90.0
56.0	.91	.000	5.46	-80.59	.4	4.2	90.0
58.0	.97	.000	5.46	-80.59	.5	5.0	90.0
60.0	1.03	.000	5.46	-80.58	.5	6.0	90.0
62.0	1.10	.000	5.46	-80.58	.6	7.1	90.0
64.0	1.18	.000	5.46	-80.58	.7	8.5	90.0
66.0	1.25	.000	5.46	-80.57	.8	10.0	90.0
68.0	1.33	.000	5.46	-80.57	.9	11.7	90.0
70.0	1.42	.000	5.46	-80.57	1.0	13.6	90.0
72.0	1.51	.000	5.46	-80.56	1.2	15.9	90.0
74.0	1.61	.000	5.46	-80.55	1.3	18.4	90.0
76.0	1.71	.000	5.46	80.55	1.5	21.2	90.0
(MAXIMUM DYNAMIC PRESSURE)							
78.0	1.82	.000	5.46	-80.54	1.6	24.3	90.0
80.0	1.92	.000	5.46	-80.54	1.8	27.8	90.0
80.0	1.92	.000	5.46	-80.54	1.8	27.8	90.0
82.0	2.03	.000	5.46	-80.53	2.0	31.6	90.0
84.0	2.14	.000	5.46	-80.52	2.2	35.8	90.0
86.0	2.25	.000	5.46	-80.51	2.4	40.4	90.0

VEHICLE ASCENT TRAJECTORY

TIME	MACH	ALPHA	LAT	LONG	HT RT	TOT HT	REL AZ
88.0	2.35	.000	5.46	-80.50	2.6	45.4	90.0
90.0	2.45	.000	5.46	-80.49	2.8	50.7	90.0
92.0	2.55	.000	5.46	-80.48	3.0	56.4	90.0
94.0	2.65	.000	5.46	-80.47	3.2	62.5	90.0
96.0	2.76	.000	5.46	-80.46	3.4	69.0	90.0
98.0	2.87	.000	5.46	-80.45	3.6	75.9	90.0
100.0	2.98	.000	5.46	-80.44	3.8	83.3	90.0
100.0	2.98	.000	5.46	-80.44	3.8	83.3	90.0
102.0	3.10	.000	5.46	-80.42	4.0	91.1	90.0
104.0	3.22	.000	5.46	-80.41	4.2	99.4	90.0
106.0	3.35	.000	5.46	-80.39	4.5	108.1	90.0
108.0	3.48	.000	5.46	-80.38	4.7	117.3	90.0
110.0	3.61	.000	5.46	-80.36	5.0	126.9	90.0
112.0	3.74	.000	5.46	-80.34	5.2	137.1	90.0
114.0	3.87	.000	5.46	-80.32	5.4	147.7	90.0
116.0	4.01	.000	5.46	-80.30	5.7	158.8	90.0
118.0	4.15	.000	5.46	-80.28	5.9	170.3	90.0
120.0	4.28	.000	5.46	-80.26	6.1	182.3	90.0
122.0	4.42	.000	5.46	-80.24	6.4	194.8	90.0
124.0	4.57	.000	5.46	-80.22	6.6	207.8	90.1
126.0	4.71	.000	5.46	-80.19	6.8	221.3	90.1
128.0	4.86	.000	5.46	-80.17	7.1	235.2	90.1
130.0	5.01	.000	5.46	-80.14	7.3	249.6	90.1
132.0	5.16	.000	5.46	-80.11	7.6	264.5	90.1
134.0	5.32	.000	5.46	-80.08	7.8	279.8	90.1
136.0	5.48	.000	5.46	-80.05	8.0	295.7	90.1
138.0	5.64	.000	5.46	-80.02	8.3	312.0	90.1
139.3	5.75	.000	5.46	-80.00	8.5	322.5	90.1
(END BOOSTER STAGE BURN)							
139.3	5.75	.000	5.46	-80.00	8.5	322.5	90.1
143.3	5.67	.000	5.46	-79.94	7.2	353.6	90.1
(BEGIN SECOND STAGE BURN)							
143.3	5.67	13.395	5.46	-79.94	7.2	353.6	90.1
151.3	5.84	14.133	5.46	-79.81	6.1	406.4	90.1
159.3	6.13	14.774	5.46	-79.67	5.4	452.1	90.1
167.3	6.47	15.322	5.46	-79.53	4.8	492.5	90.1
175.3	6.84	15.780	5.46	-79.39	4.3	528.6	90.2
183.3	7.24	16.154	5.46	-79.23	3.8	561.0	90.2
191.3	7.66	16.447	5.46	-79.08	3.5	590.2	90.2
191.3	7.66	16.446	5.46	-79.08	3.5	590.2	90.2
199.3	8.09	16.663	5.46	-78.91	3.2	616.6	90.2
207.3	8.54	16.807	5.46	-78.74	2.9	640.8	90.2
215.3	9.01	16.884	5.46	-78.56	2.7	662.9	90.3
223.3	9.49	16.897	5.46	-78.38	2.5	683.4	90.3
231.3	9.99	16.849	5.46	-78.19	2.3	702.4	90.3
239.3	10.51	16.745	5.45	-77.99	2.2	720.3	90.3
239.3	10.51	16.745	5.45	-77.99	2.2	720.3	90.3
247.3	10.89	16.589	5.45	-77.79	2.1	737.2	90.3
255.3	11.28	16.383	5.45	-77.58	2.0	753.2	90.4
263.3	11.69	16.131	5.45	-77.36	1.9	768.7	90.4
271.3	12.11	15.836	5.45	-77.13	1.9	783.9	90.4
279.3	12.47	15.501	5.45	-76.89	1.9	798.9	90.4

VEHICLE ASCENT TRAJECTORY

TIME	MACH	ALPHA	LAT	LONG	HT RT	TOT HT	REL AZ
287.3	12.81	15.130	5 44	-76 65	1.9	814.0	90.5
295.3	13.17	14.724	5 44	-76.39	1.9	829.3	90.5
303.3	13.57	14.287	5.44	-76.13	2.0	845.1	90.5
311.3	13.98	13 820	5.44	-75.86	2.1	861 6	90.6
319 3	14.43	13 327	5 43	-75.58	2.3	879.1	90.6
327.3	14 91	12.811	5 43	-75.29	2.4	897.9	90.6
335.3	15.41	12.272	5 43	-74.98	2.7	918.2	90.6
343 3	15.95	11.713	5.42	-74.67	2.9	940.6	90.7
351.3	16.52	11.137	5.42	-74.34	3 3	965.3	90 7
359.3	17.13	10 545	5.41	-74.01	3.7	992 8	90.8
367.3	17.77	9 940	5.41	-73.66	4.1	1023.9	90.8
375.3	18.45	9 323	5 40	-73.30	4.7	1059.1	90.8
383 3	19.16	8.696	5.40	-72.92	5.4	1099.2	90.9
391.3	19.92	8.061	5 39	-72.53	6.2	1145.2	90.9
399.3	20.72	7.420	5.38	-72.13	7.1	1198.1	90.9
407 3	21.56	6.773	5 38	-71 71	8.2	1259.2	91.0
415.3	22.45	6.124	5.37	-71 27	9.5	1329.9	91.0
423.3	23.38	5.474	5.36	-70.82	10.9	1411.5	91.1
431.3	24.35	4.823	5.35	-70.35	12.6	1505.5	91.1
439.3	25.37	4.174	5.34	-69.86	14.4	1613.5	91.2
447.3	26 43	3 528	5.33	-69.35	16.4	1736.6	91.2
(INJECTION)							
451.6	27.03	3 176	5.32	-69.06	17.5	1810.9	91.3

FIGURE 30 REENTRY STATE HISTORIES

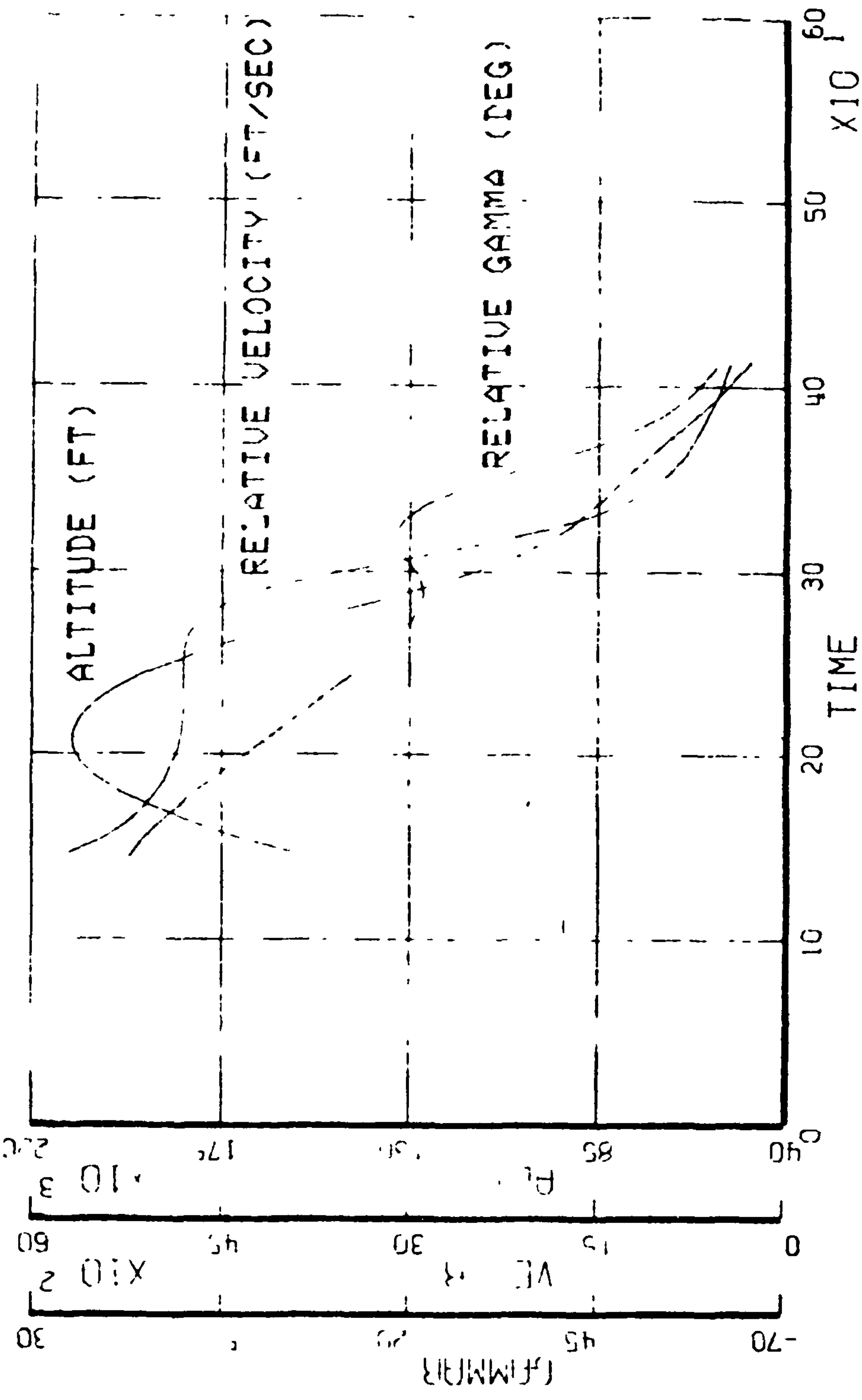


FIGURE 31 REENTRY HEATING DATA

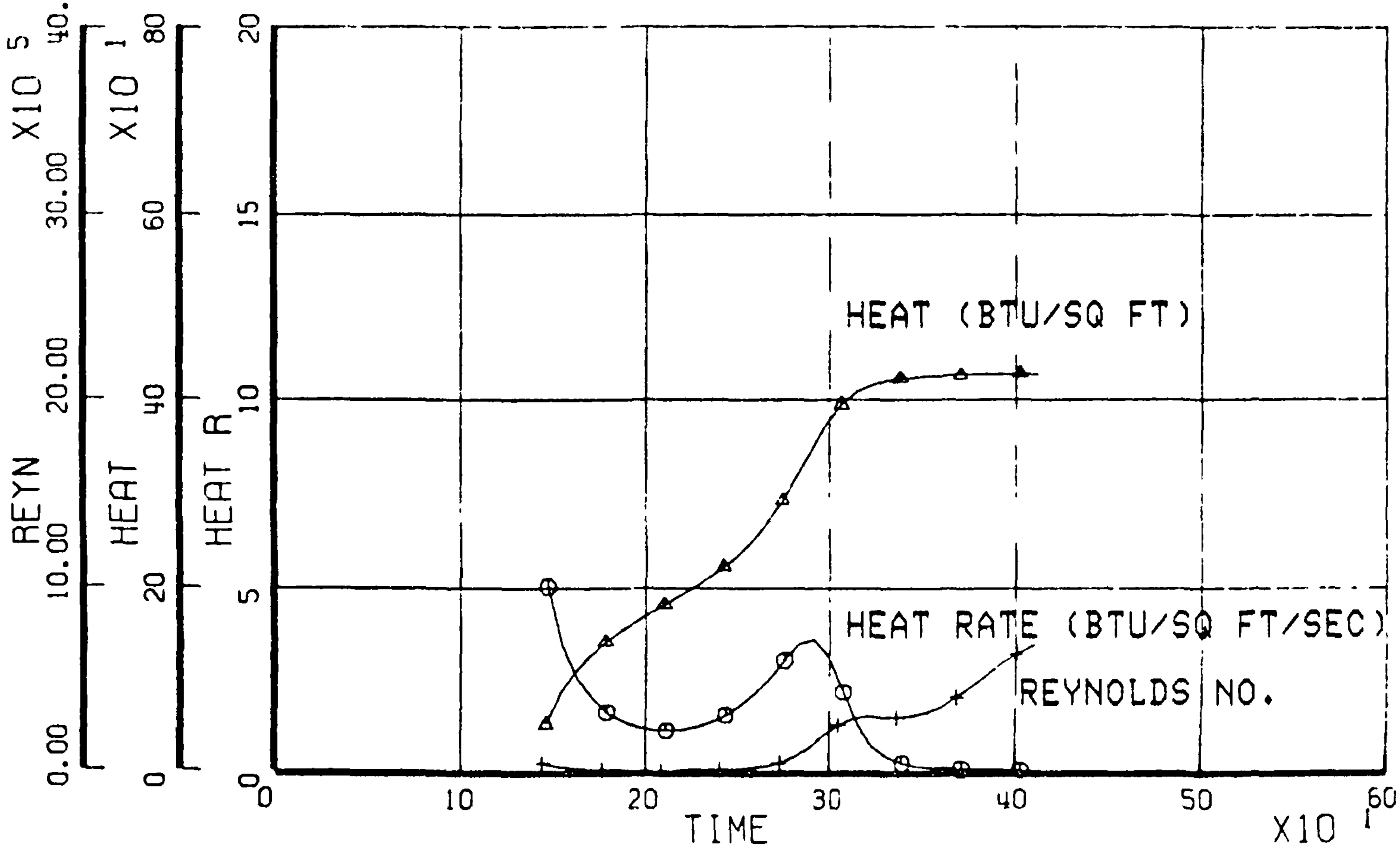


FIGURE 32 BOOSTER REENTRY TRAJECTORY

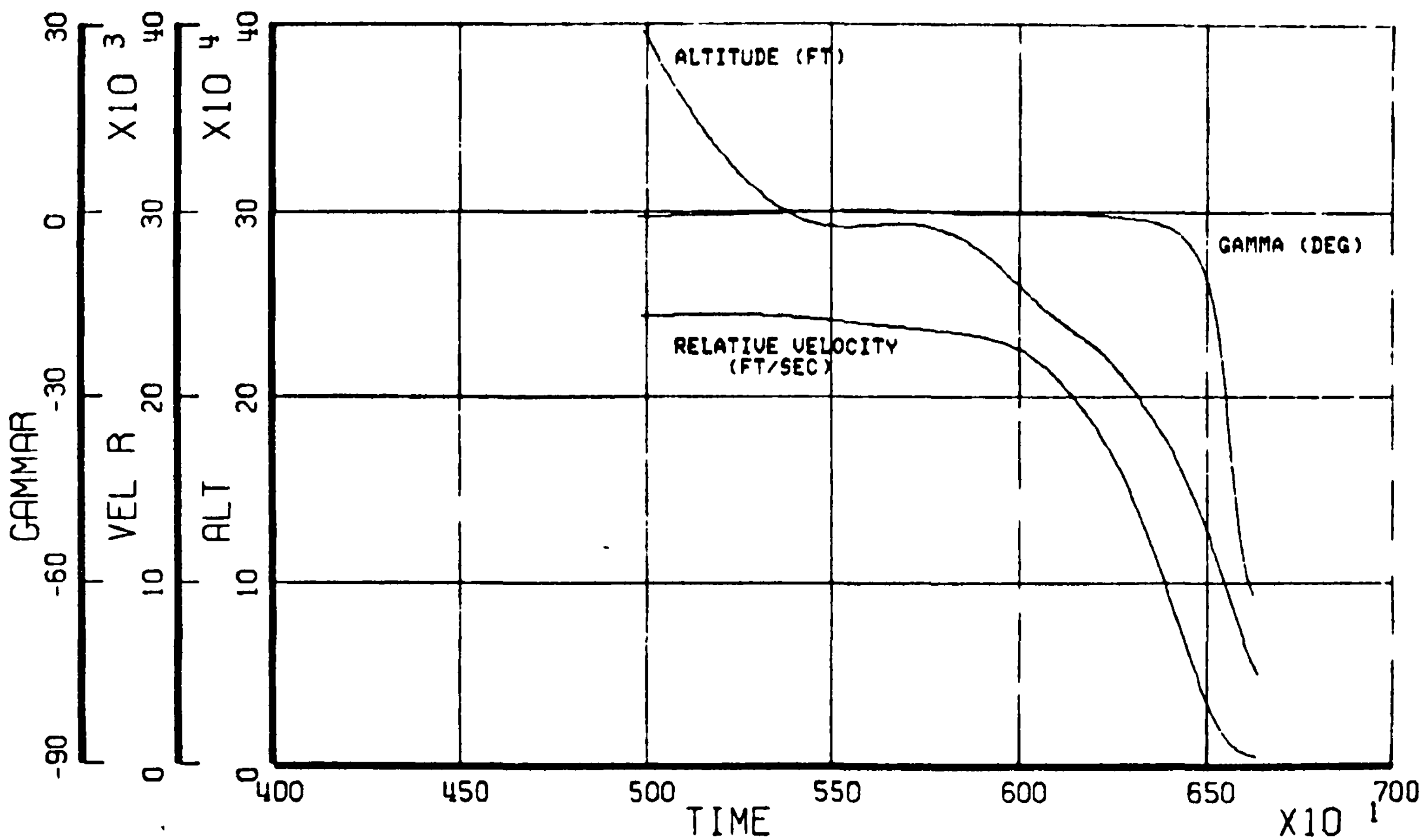
TIME (SEC)	ALT (FT)	VREL (FPS)	GAMMA R (DEG)	LAT (DEG)	LONG (DEG)	RANGE (NM)
WEIGHT =	1336369.0					
135.3	143942.2	6148.9	17.86	5.46	-80.00	.0
147.3	158276.2	5707.3	17.26	5.46	-79.88	7.4
155.3	170989.2	5443.9	15.81	5.46	-79.76	14.3
163.3	181992.5	5264.5	13.92	5.46	-79.65	21.1
171.3	191242.2	5133.9	11.75	5.46	-79.54	27.7
179 3	198713.7	5035 5	9.40	5.46	-79.43	34.2
187.3	204391.0	4960 6	6.91	5.46	-79.32	40.7
195.3	208264.5	4904.2	4.34	5.46	-79.22	47.0
203.3	210331.0	4863.2	1.71	5.46	-79.11	53.4
211.3	210591 5	4825.4	-.95	5.46	-79 01	59.7
219.3	209053.5	4818.9	-3.62	5.46	-78.90	66.0
227.3	205730.7	4811.5	-6.28	5.46	-78.80	72.3
235.3	200648 5	4810.6	-8.89	5.46	-78.69	78.5
243.3	193846.5	4912 2	-11.45	5.46	-78 59	84.7
251.3	185392 5	4810.3	-13.91	5.46	-78.49	90.8
259.3	175395 0	4795 8	-16.22	5.46	-78.39	96.8
267.3	164072 2	4754.1	-18.33	5.46	-78 29	102 8
275 3	151598 5	4660.8	-20.12	5.46	-78 19	108.6
283 3	138591 3	4473.5	-21.40	5.45	-78.10	114.2
291.3	125801 7	4141 9	-21.86	5.45	-78 01	119.5
299.3	114245.0	3642.5	-21.36	5 45	-77.93	124.2
307.3	104767.7	3032 4	-20.02	5.45	-77.86	128.3
315.3	97554.5	2430 0	-18 62	5.45	-77.80	131.7
323.3	92118 2	1934.4	-18.13	5.45	-77 76	134.4
331.3	87742.7	1526.9	-19.27	5.45	-77.72	136.5
339.3	83831.7	1258.0	-22.32	5 45	-77.69	138.2
347.3	80012 7	1057.2	-27.07	5.45	-77.67	139.6
355.3	76103.2	914.5	-32.95	5.45	-77.65	140.7
363.3	72060.5	811.1	-39.17	5.45	-77.64	141.6
371.3	67935.2	731.6	-44.97	5.45	77.62	142.4
379.3	63827.2	664.5	-49.84	5.45	-77.61	143.0
387.3	59845.0	603.7	-53.64	5.45	-77.61	143.5
395 3	56074.7	516.8	-56.46	5.45	-77.60	143.9
403.3	52554.7	497.3	-58.64	5.45	-77.59	144.3
411.3	49275.0	455.9	-60.35	5.45	-77.59	144.6
413.8	48268.7	444 3	-60.81	5.45	-77.59	144.7

FIGURE 32. BOOSTER REENTRY TRAJECTORY

TIME (SEC)	MACH	Q (PSF)	ALPHA (DEG)	HEAT (B/SF)	HT RT (B/SF/S)	REYNLD NO.
WEIGHT = 1336369.0						
139.3	5.75	88.4	60.0	.0	8.5	82270.4
147.3	5.27	43.0	60.0	52.0	5.0	42211.1
155.3	5.06	24.5	60.0	85.2	3.4	25603.4
163.3	4.97	15.4	60.0	108.7	2.5	16997.6
171.3	4.92	10.4	60.0	126.5	2.0	12080.0
179.3	4.89	7.6	60.0	140.8	1.6	9148.6
187.3	4.87	5.9	60.0	152.7	1.4	7381.8
195.3	4.85	5.0	60.0	163.1	1.2	6356.1
203.3	4.83	4.5	60.0	172.6	1.2	5850.7
211.3	4.80	4.4	60.0	181.7	1.1	5762.8
219.3	4.77	4.7	60.0	190.8	1.2	6071.0
227.3	4.73	5.3	60.0	200.2	1.2	6827.2
235.3	4.69	6.4	60.0	210.4	1.3	8168.0
243.3	4.63	8.3	60.0	221.9	1.5	10351.3
251.3	4.56	11.4	60.0	235.1	1.8	13829.7
259.3	4.49	16.2	60.0	250.7	2.1	19394.7
267.3	4.39	24.1	60.0	269.4	2.5	28446.1
275.3	4.32	37.2	60.0	291.6	3.0	45134.9
283.3	4.21	58.5	60.0	317.7	3.5	75637.8
291.3	3.97	87.0	60.0	346.3	3.6	125352.8
299.3	3.56	113.0	60.0	373.4	3.1	190681.1
307.3	3.01	121.3	60.0	394.7	2.2	251792.8
315.3	2.44	109.5	60.0	408.3	1.3	288595.9
323.3	1.94	89.2	60.0	416.0	.7	300622.6
331.3	1.56	70.2	60.0	420.2	.4	298295.8
339.3	1.28	56.7	60.0	422.5	.2	296789.8
347.3	1.08	48.3	60.0	424.0	.1	303363.4
355.3	.94	44.0	60.0	424.9	.1	322119.6
363.3	.84	42.5	60.0	425.6	.1	354950.8
371.3	.76	42.8	60.0	426.2	.1	401458.4
379.3	.70	43.9	60.0	426.6	.0	458817.4
387.3	.64	44.9	60.0	427.0	.0	522532.4
395.3	.58	45.3	60.0	427.2	.0	589292.6
403.3	.53	44.8	60.0	427.5	.0	640789.1
411.3	.48	44.1	60.0	427.7	.0	683097.0
413.8	.47	43.9	60.0	427.7	.0	694959.4

SECOND STAGE REENTRY DATA

FIGURE 33 REENTRY STATE HISTORIES



SECOND STAGE REENTRY DATA

FIGURE 34 REENTRY HEATING DATA

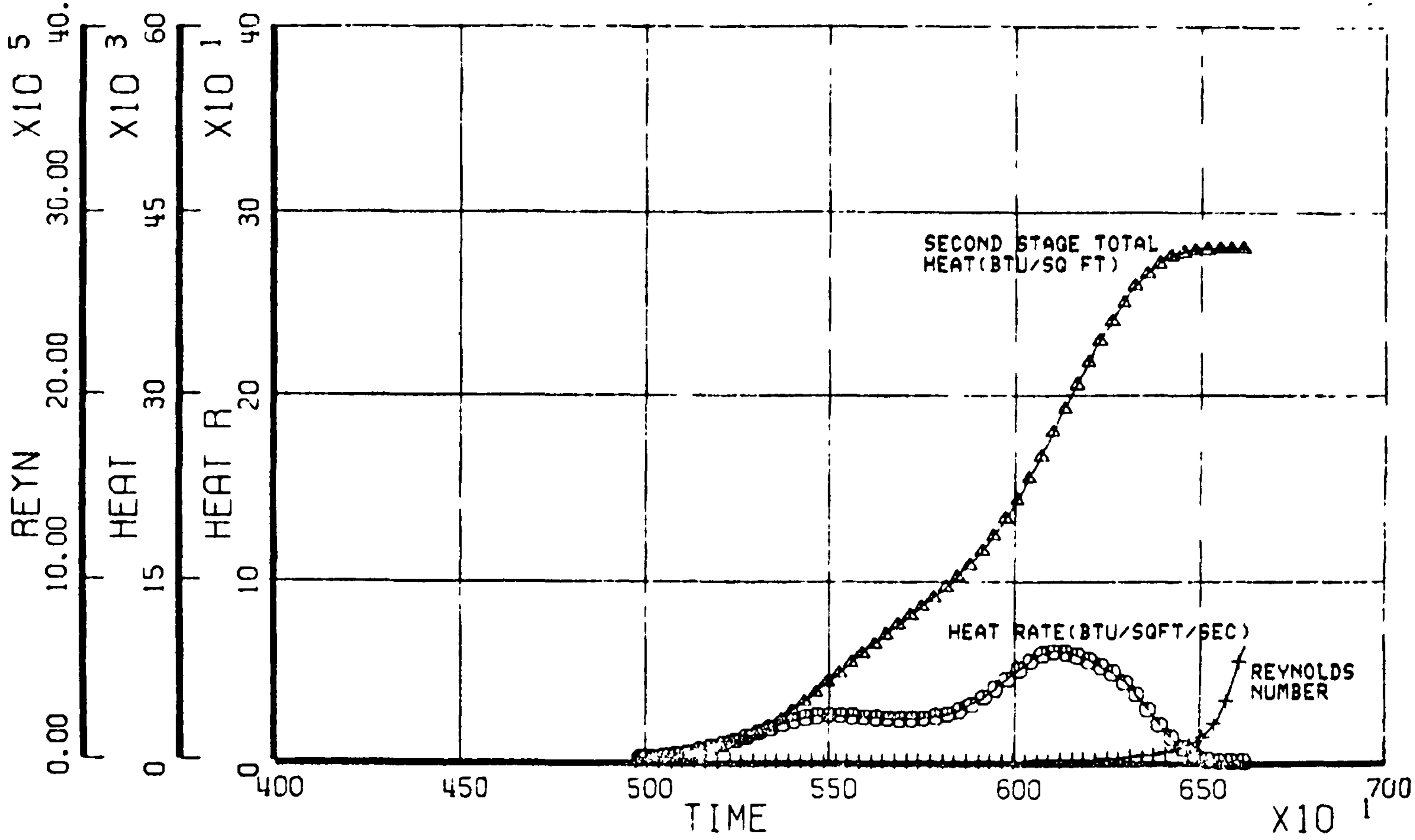


FIGURE 35. SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	ALT (FT)	VREL (FPS)	GAMMA R (DEG)	LAT (DEG)	LONG (DEG)	RANGE (NM)
WEIGHT =	728337.7					
4979.7	399999.5	24354.6	-.88	3.92	-145.61	.0
4987.7	397045.2	24358.2	-.87	3.95	-145.09	31.5
4995.7	394123.7	24361.8	-.86	3.99	-144.56	62.9
5003.7	391235.2	24365.3	-.85	4.03	-144.04	94.4
5011.7	388380.2	24368.8	-.84	4.06	-143.52	125.9
5019.7	385559.0	24372.2	-.83	4.10	-142.99	157.4
5027.7	382772.0	24375.6	-.82	4.13	-142.47	188.9
5035.7	380019.0	24378.8	-.81	4.17	-141.94	220.4
5043.7	377300.7	24382.0	-.80	4.20	-141.42	252.0
5051.7	374617.2	24385.2	-.78	4.23	-140.89	283.5
5059.7	371969.5	24388.2	-.77	4.27	-140.37	315.1
5067.7	369357.2	24391.2	-.76	4.30	-139.84	346.6
5075.7	366780.5	24394.1	-.75	4.33	-139.32	378.2
5083.7	364240.5	24396.9	-.74	4.37	-138.79	409.7
5091.7	361737.0	24399.6	-.73	4.40	-138.27	441.3
5099.7	359270.7	24402.2	-.72	4.43	-137.74	472.9
5107.7	356842.0	24404.7	-.71	4.46	-137.21	504.5
5115.7	354450.7	24407.0	-.70	4.49	-136.69	536.1
5123.7	352098.0	24409.3	-.69	4.52	-136.16	567.7
5131.7	349783.2	24411.4	-.68	4.55	-135.63	599.3
5139.7	347508.0	24413.3	-.66	4.58	-135.11	630.9
5147.7	345272.0	24415.1	-.65	4.61	-134.58	662.5
5155.7	343075.7	24416.7	-.64	4.64	-134.05	694.1
5163.7	340919.7	24418.2	-.63	4.67	-133.52	725.8
5171.7	338804.7	24419.4	-.62	4.69	-133.00	757.4
5179.7	336730.7	24420.4	-.60	4.72	-132.47	789.0
5187.7	334698.7	24421.2	-.59	4.75	-131.94	820.7
5195.7	332709.2	24421.7	-.58	4.77	-131.42	852.3
5203.7	330762.2	24422.0	-.57	4.80	-130.89	884.0
5211.7	328859.2	24421.9	-.55	4.82	-130.36	915.6
5219.7	327000.5	24421.6	-.54	4.85	-129.83	947.3
5227.7	325186.7	24420.9	-.53	4.87	-129.30	979.0
5235.7	323418.5	24419.8	-.51	4.90	-128.78	1010.6
5243.7	321696.5	24418.4	-.50	4.92	-128.25	1042.3
5251.7	320022.0	24416.6	-.49	4.94	-127.72	1073.9
5259.7	318394.5	24414.3	-.47	4.97	-127.19	1105.6
5267.7	316815.7	24411.6	-.46	4.99	-126.66	1137.3
5275.7	315286.5	24408.4	-.44	5.01	-126.13	1168.9
5283.7	313807.7	24404.6	-.43	5.03	-125.61	1200.6
5291.7	312379.2	24400.4	-.41	5.05	-125.08	1232.2
5299.7	311003.2	24395.6	-.40	5.07	-124.55	1263.9
5307.7	309678.7	24390.2	-.38	5.09	-124.02	1295.5
5315.7	308408.5	24384.2	-.37	5.11	-123.49	1327.2
5323.7	307191.7	24377.6	-.35	5.13	-122.97	1358.8
5331.7	306030.2	24370.3	-.33	5.15	-122.44	1390.5
5339.7	304923.7	24362.4	-.32	5.17	-121.91	1422.1
5347.7	303873.5	24353.8	-.30	5.18	-121.38	1453.7
5355.7	302880.0	24344.5	-.29	5.20	-120.85	1485.3

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	ALT (FT)	VREL (FPS)	GAMMA R (DEG)	LAT (DEG)	LONG (DEG)	RANGE (NM)
5363.7	301943.7	24334.5	-.27	5.22	-120.33	1516.9
5371.7	301064.5	24323.9	-.25	5.23	-119.80	1548.5
5379.7	300243.0	24312.6	-.23	5.25	-119.27	1580.0
5387.7	299479.2	24300.7	-.22	5.26	-118.74	1611.6
5395.7	298773.5	24288.1	-.20	5.28	-118.22	1643.1
5403.7	298125.2	24274.9	-.18	5.29	-117.69	1674.6
5411.7	297533.7	24261.1	-.17	5.30	-117.17	1706.1
5419.7	296999.2	24246.7	-.15	5.32	-116.64	1737.6
5427.7	296520.2	24231.8	-.13	5.33	-116.11	1769.1
5435.7	296096.5	24216.5	-.12	5.34	-115.59	1800.5
5443.7	295725.7	24200.7	-.10	5.35	-115.06	1832.0
5451.7	295407.5	24184.5	-.09	5.36	-114.54	1863.4
5459.7	295140.0	24168.0	-.07	5.37	-114.01	1894.8
5467.7	294921.5	24151.2	-.06	5.38	-113.49	1926.1
5475.7	294749.5	24134.2	-.04	5.39	-112.97	1957.5
5483.7	294622.2	24117.0	-.03	5.40	-112.44	1988.8
5491.7	294537.5	24099.7	-.02	5.41	-111.92	2020.1
5499.7	294492.0	24082.3	.01	5.41	-111.40	2051.4
5507.7	294483.7	24064.8	.00	5.42	-110.88	2082.6
5515.7	294510.0	24047.3	.01	5.43	-110.35	2113.9
5523.7	294567.2	24029.9	.02	5.43	-109.83	2145.1
5531.7	294653.2	24012.5	.03	5.44	-109.31	2176.3
5539.7	294764.0	23995.2	.04	5.44	-108.79	2207.4
5547.7	294897.2	23978.0	.04	5.45	-108.27	2238.6
5555.7	295049.5	23960.9	.05	5.45	-107.75	2269.7
5563.7	295218.0	23944.0	.05	5.46	-107.23	2300.8
5571.7	295399.2	23927.3	.06	5.46	-106.71	2331.9
5579.7	295589.7	23910.6	.06	5.46	-106.19	2362.9
5587.7	295786.5	23894.4	.06	5.46	-105.67	2394.0
5595.7	295986.5	23878.3	.06	5.46	-105.15	2425.0
5603.7	296186.5	23862.4	.06	5.47	-104.64	2456.0
5611.7	296383.5	23846.7	.06	5.47	-104.12	2486.9
5619.7	296573.7	23831.2	.06	5.47	-103.60	2517.9
5627.7	296755.2	23815.9	.05	5.47	-103.08	2548.8
5635.7	296924.2	23800.8	.05	5.46	-102.57	2579.7
5643.7	297078.2	23785.9	.04	5.46	-102.05	2610.6
5651.7	297214.7	23771.2	.04	5.46	-101.54	2641.5
5659.7	297330.5	23756.6	.03	5.46	-101.02	2672.3
5667.7	297423.7	23742.2	.02	5.45	-100.50	2703.2
5675.7	297491.2	23727.8	.02	5.45	-99.99	2734.0
5683.7	297530.7	23713.6	.01	5.45	-99.48	2764.8
5691.7	297540.0	23699.5	-.00	5.44	-98.96	2795.6
5699.7	297516.7	23685.4	-.01	5.44	-98.45	2826.3
5707.7	297459.0	23671.3	-.02	5.43	-97.93	2857.1
5715.7	297365.0	23657.3	-.03	5.43	-97.42	2887.8
5723.7	297232.0	23643.2	-.05	5.42	-96.91	2918.5
5731.7	297059.0	23629.0	-.06	5.41	-96.39	2949.2
5739.7	296843.7	23614.7	-.07	5.41	-95.88	2979.8
5747.7	296585.0	23600.4	-.08	5.40	-95.37	3010.5
5755.7	296281.2	23585.8	-.10	5.39	-94.86	3041.1
5763.7	295930.7	23571.0	-.11	5.38	-94.35	3071.7

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	ALT (FT)	VREL (FPS)	GAMMA R (DEG)	LAT (DEG)	LONG (DEG)	RANGE (NM)
5771.7	295533.0	23556.0	-.13	5.37	-93.84	3102.3
5779.7	295086.2	23540.6	-.14	5.36	-93.32	3132.9
5787.7	294590.0	23524.9	-.16	5.35	-92.81	3163.5
5795.7	294042.7	23508.8	-.17	5.34	-92.30	3194.0
5803.7	293443.7	23492.2	-.19	5.33	-91.79	3224.5
5811.7	292792.7	23475.1	-.21	5.32	-91.28	3255.0
5819.7	292088.7	23457.4	-.22	5.30	-90.78	3285.5
5827.7	291332.0	23439.1	-.24	5.29	-90.27	3315.9
5835.7	290521.7	23420.0	-.25	5.28	-89.76	3346.3
5843.7	289658.5	23400.0	-.27	5.26	-89.25	3376.7
5851.7	288741.7	23379.0	-.29	5.25	-88.74	3407.1
5859.7	287773.0	23357.0	-.30	5.24	-88.24	3437.5
5867.7	286752.2	23333.7	-.32	5.22	-87.73	3467.8
5875.7	285680.5	23309.1	-.34	5.21	-87.22	3498.1
5883.7	284559.5	23283.0	-.35	5.19	-86.72	3528.3
5891.7	283390.7	23255.1	-.37	5.17	-86.22	3558.6
5899.7	282175.5	23225.4	-.38	5.16	-85.71	3588.8
5907.7	280917.2	23193.5	-.39	5.14	-85.21	3618.9
5915.7	279618.2	23159.4	-.41	5.12	-84.70	3649.0
5923.7	278281.7	23122.6	-.42	5.10	-84.20	3679.1
5931.7	276911.5	23083.0	-.43	5.09	-83.70	3709.1
5939.7	275511.7	23040.3	-.44	5.07	-83.20	3739.1
5947.7	274087.5	22994.1	-.45	5.05	-82.70	3769.0
5955.7	272643.7	22944.1	-.45	5.03	-82.20	3798.8
5963.7	271186.7	22890.1	-.46	5.01	-81.71	3828.6
5971.7	269721.2	22832.1	-.46	4.99	-81.21	3858.3
5979.7	268253.0	22769.9	-.46	4.97	-80.72	3888.0
5987.7	266787.5	22703.2	-.46	4.95	-80.22	3917.5
5995.7	265330.0	22631.6	-.46	4.92	-79.73	3947.0
6003.7	263886.5	22555.1	-.45	4.90	-79.24	3976.4
6011.7	262463.2	22473.4	-.45	4.88	-78.75	4005.7
6019.7	261065.2	22386.3	-.44	4.86	-78.27	4034.8
6027.7	259698.2	22293.7	-.43	4.83	-77.78	4063.9
6035.7	258367.0	22195.5	-.42	4.81	-77.30	4092.8
6043.7	257076.0	22091.7	-.41	4.79	-76.82	4121.6
6051.7	255829.2	21982.2	-.40	4.76	-76.34	4150.3
6059.7	254628.5	21867.2	-.38	4.74	-75.87	4178.8
6067.7	253476.7	21746.6	-.37	4.72	-75.39	4207.2
6075.7	252373.7	21620.8	-.36	4.69	-74.92	4235.4
6083.7	251319.0	21489.8	-.34	4.67	-74.46	4263.4
6091.7	250310.5	21353.8	-.33	4.64	-73.99	4291.3
6099.7	249345.5	21213.2	-.32	4.62	-73.53	4319.0
6107.7	248418.7	21068.1	-.31	4.59	-73.07	4346.5
6115.7	247525.0	20918.7	-.30	4.57	-72.62	4373.8
6123.7	246657.2	20765.3	-.29	4.54	-72.16	4400.9
6131.7	245807.7	20608.1	-.29	4.52	-71.72	4427.9
6139.7	244967.7	20447.1	-.29	4.49	-71.27	4454.6
6147.7	244128.5	20282.4	-.30	4.46	-70.83	4481.1
6155.7	243279.7	20114.0	-.30	4.44	-70.39	4507.4
6163.7	242412.5	19941.9	-.31	4.41	-69.96	4533.4
6171.7	241517.5	19765.9	-.33	4.39	-69.53	4559.3

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	ALT (FT)	VREL (FPS)	GAMMA R (DEG)	LAT (DEG)	LONG (DEG)	RANGE (NM)
6179.7	240585.2	19595.9	-.35	4.36	-69.10	4584.9
6187.7	239608.0	19401.4	-.37	4.33	-68.68	4610.0
6195.7	238579.0	19212.3	-.39	4.31	-68.26	4635.4
6203.7	237439.5	19018.0	-.42	4.28	-67.84	4660.3
6211.7	236334.7	18816.1	-.45	4.25	-67.43	4684.9
6219.7	235112.7	18612.0	-.48	4.23	-67.03	4709.3
6227.7	233820.2	18399.2	-.52	4.20	-66.63	4733.4
6235.7	232456.7	18179.0	-.55	4.18	-66.23	4757.2
6243.7	231023.0	17950.8	-.58	4.15	-65.84	4780.7
6251.7	229521.2	17714.0	-.62	4.12	-65.45	4803.9
6259.7	227956.0	17468.1	-.65	4.10	-65.07	4826.8
6267.7	226331.5	17212.4	-.69	4.07	-64.70	4849.4
6275.7	224654.5	16946.5	-.72	4.05	-64.33	4871.7
6283.7	222931.7	16670.0	-.75	4.02	-63.96	4893.6
6291.7	221170.7	16382.6	-.78	3.99	-63.60	4915.1
6299.7	219378.0	16084.3	-.80	3.97	-63.25	4936.2
6307.7	217560.5	15775.1	-.83	3.94	-62.91	4957.0
6315.7	215724.5	15455.0	-.85	3.92	-62.57	4977.4
6323.7	213873.7	15124.5	-.88	3.90	-62.24	4997.3
6331.7	212011.5	14794.0	-.90	3.87	-61.91	5016.8
6339.7	210138.0	14434.0	-.93	3.85	-61.60	5035.8
6347.7	208252.0	14075.3	-.96	3.83	-61.29	5054.4
6355.7	206350.2	13708.4	-1.00	3.80	-60.99	5072.5
6363.7	204427.2	13334.1	-1.04	3.78	-60.69	5090.1
6371.7	202475.2	12953.1	-1.09	3.76	-60.41	5107.3
6379.7	200486.0	12566.0	-1.14	3.74	-60.13	5123.9
6387.7	198449.2	12173.5	-1.21	3.72	-59.86	5140.0
6395.7	196355.0	11776.0	-1.29	3.70	-59.60	5155.6
6403.7	194191.7	11372.9	-1.38	3.68	59.35	5170.7
6411.7	191949.7	10967.7	-1.49	3.66	-59.11	5185.3
6419.7	189619.0	10557.6	-1.61	3.64	-58.88	5199.4
6427.7	187190.5	10143.9	-1.75	3.62	-58.65	5212.9
6435.7	184656.2	9726.8	-1.91	3.60	-58.44	5225.8
6443.7	182009.5	9306.8	-2.08	3.58	-58.23	5238.2
6451.7	179245.0	8884.2	-2.28	3.57	-58.04	5250.1
6459.7	176358.2	8459.3	-2.50	3.55	-57.85	5261.4
6467.7	173347.0	8032.8	-2.74	3.54	-57.67	5272.2
6475.7	170208.0	7605.4	-3.02	3.52	-57.50	5282.4
6483.7	166939.0	7177.8	-3.33	3.51	-57.34	5292.0
6491.7	163539.5	6751.2	-3.68	3.50	-57.19	5301.1
6499.7	160007.7	6326.5	-4.07	3.48	-57.05	5309.6
6507.7	156347.0	5902.8	-4.52	3.47	-56.91	5317.6
6515.7	152567.0	5480.3	-5.02	3.46	-56.79	5325.0
6523.7	148679.0	5061.0	-5.58	3.45	-56.68	5331.8
6531.7	144691.2	4646.9	-6.23	3.44	-56.57	5338.2
6539.7	140610.2	4240.7	-6.98	3.43	-56.48	5343.9
6547.7	136438.2	3845.5	-7.88	3.42	-56.39	5349.2
6555.7	132174.0	3464.4	-8.95	3.41	-56.31	5353.9
6563.7	127813.7	3100.5	-10.24	3.41	-56.24	5358.1
6571.7	123353.7	2756.9	-11.80	3.40	-56.18	5361.9
6579.7	118769.0	2436.5	-13.70	3.39	-56.12	5365.2

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	ALT (FT)	VREL (FPS)	GAMMA R (DEG)	LAT (DEG)	LONG (DEG)	RANGE (NM)
6587.7	114118.5	2141.7	-16.00	3.39	-56.08	5368.1
6595.7	109347.2	1874.2	-18.74	3.38	-56.04	5370.6
6603.7	104487.2	1635.3	-21.99	3.38	-56.00	5372.8
6611.7	99560.0	1425.4	-25.73	3.37	-55.97	5374.6
6619.7	94600.7	1243.7	-29.91	3.37	-55.94	5376.1
6627.7	89653.5	1088.6	-34.43	3.36	-55.92	5377.4
6635.7	84770.7	956.2	-39.08	3.36	-55.91	5378.2
6643.7	80009.0	848.2	-43.61	3.36	-55.89	5377.3
6651.7	75429.0	754.7	-47.77	3.35	-55.88	5376.6
6659.7	71085.0	674.3	-51.34	3.35	-55.87	5376.0
6667.7	67014.2	604.8	-54.24	3.35	-55.86	5375.4
6675.7	63235.5	544.8	-56.45	3.35	-55.85	5375.0
6683.7	59747.2	493.3	-58.03	3.34	-55.85	5374.6
6691.7	56537.5	448.5	-59.03	3.34	-55.84	5374.3
6699.7	53581.2	411.8	-59.68	3.34	-55.84	5374.0
6707.7	50839.2	381.9	-60.03	3.34	-55.84	5373.8
6710.4	49954.5	373.1	-60.09	3.33	-55.84	5373.7

FIGURE 35. SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	MACH	Q (PSF)	ALPHA (DEG)	HEAT (B/SF)	HT RT (B/SF/S)	REYNLD NO.
WEIGHT =	728337.7					
4979.7	18.54	.0	60.0	.0	1 8	2.0
4987.7	18.97	.0	60.0	15.2	2.0	2.3
4995.7	19.44	.0	60.0	31.4	2.1	2.7
5003.7	19.71	.0	60.0	48.7	2.2	3.0
5011.7	19.96	.0	60.0	66.8	2.3	3.5
5019.7	20.22	.0	60.0	86.0	2.5	3.9
5027.7	20.48	.0	60.0	106.3	2.6	4.5
5035.7	20.76	.0	60.0	127.7	2.8	5.1
5043 7	21.03	.0	60.0	150.4	2.9	5.8
5051.7	21.32	0	60.0	174.4	3.1	6.7
5059 7	21.61	.0	60.0	199 9	3 3	7.6
5067.7	21.91	.0	60.0	226.9	3.5	8.8
5075.7	22.22	.0	60.0	255.5	3.7	10.1
5083 7	22.54	.1	60.0	286.0	3.9	11.7
5091.7	22.87	.1	60.0	318 3	4.2	13.5
5099.7	23.09	.1	60.0	352.7	4.4	15.4
5107 7	23.26	1	60.0	389.0	4.7	17.4
5115.7	23 43	.1	60.0	427.4	4.9	19 6
5123.7	23.60	.1	60.0	468.0	5.2	22.1
5131.7	23.78	.1	60.0	510.9	5.5	25.0
5139.7	23.95	.1	60.0	556.2	5.9	28.2
5147.7	24.12	.1	60.0	604.0	6.1	31.8
5155.7	24.30	.1	60.0	654.5	6 5	35.8
5163.7	24.47	.2	60.0	707.8	6.8	40.3
5171.7	24.64	.2	60.0	764.1	7.2	45.4
5179.7	24.82	2	60.0	823.4	7.6	51.2
5187.7	24.99	.2	60.0	886.0	8.0	57.5
5195.7	25.17	.2	60.0	952.1	8.5	64.7
5203.7	25.34	.3	60.0	1021 6	8.9	72.6
5211.7	25.51	.3	60.0	1094.9	9.4	81.5
5219.7	25.64	.3	60.0	1172.0	9.9	90.7
5227.7	25.75	.4	60.0	1253 0	10.4	100.5
5235.7	25.85	.4	60.0	1337.8	10.9	111.1
5243.7	25.94	.4	60.0	1426.7	11.4	122.6
5251.7	26.04	5	60.0	1519.7	11.9	135.1
5259.7	26.13	.5	60.0	1616.9	12.4	148.5
5267.7	26.22	.6	60.0	1718.4	13.0	162.8
5275.7	26.31	.6	60.0	1824.3	13.5	178.2
5283.7	26.40	.7	60.0	1934.7	14.1	194.5
5291.7	26.48	.7	60.0	2049.5	14.6	211.9
5299.7	26.56	.8	60.0	2168.9	15.2	230.1
5307.7	26.64	.8	60.0	2292.9	15.8	249.3
5315.7	26.71	.9	60.0	2421.4	16.3	269.4
5323.7	26.78	.9	60.0	2554 4	16.9	290.2
5331.7	26.85	1.0	60.0	2691.9	17.5	311.7
5339.7	26.91	1.1	60.0	2833.9	18.0	333.8
5347.7	26.97	1.1	60.0	2980.3	18.6	356.3
5355.7	27.02	1.2	60.0	3130.9	19.1	379.1
5363.7	27.08	1.3	60.0	3285.6	19.6	402.0
5371.7	27.12	1.3	60.0	3444.4	20.1	424.9

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	MACH	Q (PSF)	ALPHA (DEG)	HEAT (B/SF)	HT RT (B/SF/S)	REYNLD NO.
5379.7	27.16	1.4	60.0	3606.9	20.5	447.5
5387.7	27.20	1.5	60.0	3773.1	21.0	469.7
5395.7	27.24	1.5	60.0	3942 7	21.4	491.2
5403.7	27.27	1.6	60.0	4115.5	21 8	511.8
5411.7	27.29	1.7	60.0	4291.2	22.1	531.5
5419.7	27.31	1.7	60.0	4469.6	22.5	549.9
5427.7	27 33	1.8	60.0	4650.4	22.7	566.9
5435.7	27.34	1.8	60.0	4833.4	23.0	582.4
5443 7	27.35	1.8	60.0	5018.2	23.2	596.3
5451.7	27.35	1.9	60.0	5204.5	23.4	608.4
5459.7	27.34	1 9	60.0	5392.1	23.5	617.9
5467.7	27 32	1.9	60.0	5580.6	23.6	625.1
5475.7	27.30	1 9	60.0	5769.6	23.7	630.7
5483 7	27.28	1 9	60.0	5959.1	23.7	634.8
5491 7	27.26	2.0	60 0	6148.7	23.7	637.3
5499.7	27.24	2.0	60.0	6338 2	23.7	638.5
5507.7	27.22	2.0	60.0	6527.5	23.6	638.3
5515.7	27.20	1.9	60.0	6716.2	23.6	636.9
5523.7	27.18	1.9	60.0	6904.3	23.5	634.4
5531.7	27.16	1.9	60.0	7091.6	23.4	630.9
5539.7	27.14	1.9	60.0	7277.9	23.2	626.6
5547.7	27 13	1.9	60.0	7463.2	23.1	621.5
5555.7	27.11	1.9	60.0	7647.3	22.9	615.7
5563.7	27.09	1.9	60.0	7830.2	22.8	609.5
5571.7	27 06	1.8	60.0	8011.8	22.6	602.3
5579 7	27.03	1.8	60.0	8191.9	22.4	594.4
5587 7	27.00	1.8	60.0	8370.7	22.2	586.4
5595.7	26.96	1.8	60.0	8547.9	22.1	578.4
5603 7	26.93	1.7	60.0	8723.7	21.9	570.5
5611 7	26.90	1.7	60.0	8898.1	21.7	562.9
5619.7	26.87	1.7	60.0	9071.1	21.5	555.6
5627.7	26.84	1.7	60.0	9242.8	21.4	548.7
5635 7	26.81	1.7	60.0	9413.3	21.2	542.4
5643.7	26.79	1.6	60.0	9582.5	21.1	536.7
5651 7	26.76	1.6	60.0	9750.7	21.0	531.6
5659.7	26.74	1.6	60.0	9917.9	20.8	527.3
5667.7	26.71	1.6	60.0	10084.3	20.7	523.8
5675.7	26.69	1.6	60.0	10250.0	20.7	521.2
5683.7	26.67	1.6	60.0	10415.1	20.6	519.6
5691 7	26 66	1.6	60.0	10579.7	20.6	519.0
5699.7	26.64	1.6	60.0	10744.1	20.5	519.4
5707.7	26.63	1.6	60.0	10908.3	20.5	521.1
5715 7	26.62	1.6	60.0	11072.7	20.6	523.9
5723 7	26.61	1.6	60.0	11237.3	20.6	528.2
5731.7	26.61	1.6	60.0	11402 3	20.7	533.8
5739 7	26.61	1.6	60.0	11568.0	20 8	541.0
5747.7	26.61	1.7	60.0	11734.5	20.9	549.8
5755.7	26 61	1.7	60.0	11902.2	21.0	560.4
5763 7	26.62	1.7	60.0	12071.2	21.2	573.0
5771.7	26.63	1.8	60.0	12241.8	21.4	587.7
5779.7	26.63	1.8	60.0	12414.2	21.7	603.7

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	MACH	Q (PSF)	ALPHA (DEG)	HEAT (B/SF)	HT RT (B/SF/S)	REYNLD NU.
5787.7	26.61	1.9	60.0	12588.6	21.9	620.3
5795.7	26.59	1.9	60.0	12765.2	22.2	639.1
5803.7	26.58	2.0	60.0	12944.3	22.5	660.5
5811.7	26.56	2.0	60.0	13126.1	22.9	684.5
5819.7	26.54	2.1	60.0	13310.9	23.2	711.5
5927.7	26.52	2.2	60.0	13479.1	23.7	741.7
5835.7	26.49	2.3	60.0	13691.0	21.2	775.4
5343.7	26.47	2.4	60.0	13687.0	24.8	813.1
5851.7	26.45	2.5	60.0	14087.3	25.3	855.2
5559.7	26.42	2.7	60.0	14292.4	25.9	902.0
5867.7	26.40	2.8	60.0	14502.6	26.6	954.1
5975.7	26.37	3.0	60.0	14718.4	27.3	1012.1
5862.7	26.34	3.2	60.0	14940.2	28.1	1076.5
5891.7	26.31	3.4	60.0	15168.4	28.9	1147.9
5899.7	26.27	3.6	60.0	15403.3	29.6	1227.2
5907.7	26.24	3.9	60.0	15645.6	30.6	1315.1
5915.7	26.20	4.2	60.0	15895.6	31.7	1412.3
5923.7	26.16	4.5	60.0	16153.7	32.8	1519.7
5931.7	26.11	4.8	60.0	16420.4	33.9	1638.2
5939.7	26.06	5.2	60.0	16696.2	35.0	1768.7
5947.7	26.01	5.6	60.0	16981.3	36.2	1911.9
5955.7	25.96	6.0	60.0	17276.2	37.5	2068.6
5963.7	25.82	6.5	60.0	17580.7	38.6	2214.9
5971.7	25.67	6.9	60.0	17834.4	39.9	2364.5
5979.7	25.51	7.4	60.0	18217.2	40.9	2523.4
5987.7	25.35	7.9	60.0	18549.2	42.1	2691.5
5995.7	25.18	8.5	60.0	18890.3	43.2	2868.5
6003.7	25.01	9.1	60.0	19240.1	44.3	3053.5
6011.7	24.84	9.6	60.0	19598.6	45.3	3245.8
6019.7	24.67	10.3	60.0	19965.5	46.4	3444.4
6027.7	24.50	10.9	60.0	20340.2	47.3	3648.0
6035.7	24.32	11.5	60.0	20722.3	48.2	3855.3
6043.7	24.14	12.1	60.0	21111.0	49.0	4064.8
6051.7	23.96	12.7	60.0	21505.8	49.7	4274.9
6059.7	23.77	13.4	60.0	21905.8	50.3	4484.3
6067.7	23.58	13.9	60.0	22310.4	50.8	4691.4
6075.7	23.39	14.5	60.0	22718.5	51.2	4895.0
6083.7	23.20	15.1	60.0	23129.4	51.5	5094.2
6091.7	23.00	15.6	60.0	23542.3	51.7	5288.5
6099.7	22.81	16.1	60.0	23956.2	51.8	5477.3
6107.7	22.61	16.6	60.0	24370.6	51.8	5661.2
6115.7	22.40	17.1	60.0	24784.5	51.7	5840.5
6123.7	22.20	17.5	60.0	25197.5	51.5	6016.5
6131.7	21.99	17.9	60.0	25608.9	51.3	6190.6
6139.7	21.78	18.3	60.0	26018.3	51.0	6364.7
6147.7	21.57	18.7	60.0	26425.3	50.7	6541.0
6155.7	21.36	19.2	60.0	26829.6	50.4	6722.2
6163.7	21.13	19.6	60.0	27230.9	50.0	6911.1
6171.7	20.91	20.0	60.0	27629.3	49.6	7110.6
6179.7	20.68	20.5	60.0	28024.6	49.2	7323.8
6187.7	20.44	21.0	60.0	28416.8	48.8	7553.8

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	MACH	Q (PSF)	ALPHA (DEG)	HEAT (B/SF)	HT RT (B/SF/S)	REYNLD NO.
6195.7	20.20	21.6	60.0	28805.9	48.4	7603.8
6203.7	19.95	22.2	60.0	29191.9	48.1	8077.0
6211.7	19.70	22.9	60.0	29574.9	47.7	8576.3
6219.7	19.43	23.6	60.0	29955.0	47.3	8704.5
6227.7	19.16	24.4	60.0	30332.0	46.9	9064.1
6235.7	18.88	25.3	60.0	30706.0	46.6	9457.2
6243.7	18.58	26.2	60.0	31076.8	46.1	9885.5
6251.7	18.28	27.3	60.0	31444.2	45.7	10350.0
6259.7	17.97	28.3	60.0	31807.9	45.2	10851.1
6267.7	17.65	29.5	60.0	32167.5	44.7	11388.7
6275.7	17.32	30.6	60.0	32522.4	44.1	11961.5
6283.7	16.97	31.9	60.0	32872.1	43.4	12567.7
6291.7	16.62	33.1	60.0	33215.9	42.6	13204.7
6299.7	16.26	34.3	60.0	33553.0	41.7	13869.5
6307.7	15.89	35.6	60.0	33882.5	40.7	14558.5
6315.7	15.51	36.8	60.0	34203.6	39.6	15267.7
6323.7	15.12	37.9	60.0	34515.6	38.4	15994.0
6331.7	14.72	39.0	60.0	34817.4	37.1	16734.2
6339.7	14.32	40.1	60.0	35108.4	35.7	17486.7
6347.7	13.91	41.0	60.0	35388.0	34.2	18250.6
6355.7	13.50	41.9	60.0	35655.4	32.7	19026.5
6363.7	13.08	42.7	60.0	35910.3	31.1	19816.7
6371.7	12.66	43.5	60.0	36152.3	29.4	20625.5
6379.7	12.24	44.1	60.0	36381.2	27.8	21458.1
6387.7	11.81	44.7	60.0	36596.9	26.1	22321.6
6395.7	11.38	45.3	60.0	36799.5	24.5	23224.5
6403.7	10.95	45.8	60.0	36988.9	22.9	24176.1
6411.7	10.52	46.3	60.0	37165.3	21.3	25186.3
6419.7	10.08	46.8	60.0	37329.1	19.7	26265.6
6427.7	9.65	47.3	60.0	37480.4	18.2	27425.2
6435.7	9.22	47.7	60.0	37619.6	16.7	28676.7
6443.7	8.78	48.1	60.0	37747.1	15.2	30031.9
6451.7	8.35	48.5	60.0	37863.2	13.8	31502.7
6459.7	7.92	48.8	60.0	37968.4	12.5	33102.3
6467.7	7.49	49.1	60.0	38063.1	11.2	34843.7
6475.7	7.07	49.3	60.0	38147.7	10.0	36743.5
6483.7	6.65	49.4	60.0	38222.9	8.8	38820.9
6491.7	6.24	49.4	60.0	38289.0	7.7	41096.9
6499.7	5.83	49.4	60.0	38346.8	6.7	43720.0
6507.7	5.45	49.5	60.0	38396.8	5.8	47133.1
6515.7	5.08	49.5	60.0	38439.8	4.9	50999.2
6523.7	4.71	49.4	60.0	38476.1	4.2	55345.3
6531.7	4.34	48.9	60.0	38506.5	3.4	60200.3
6539.7	3.98	48.3	60.0	38531.5	2.8	65593.0
6547.7	3.63	47.3	60.0	38551.7	2.3	71562.2
6555.7	3.29	46.1	60.0	38567.8	1.8	78160.6
6563.7	2.97	44.6	60.0	38580.4	1.4	85462.4
6571.7	2.66	43.0	60.0	38590.1	1.1	93565.4
6579.7	2.36	41.2	60.0	38597.4	.8	102613.5
6587.7	2.09	39.3	60.0	38602.9	.6	112797.7
6595.7	1.85	37.5	60.0	38606.9	.4	124371.4

SECOND STAGE REENTRY TRAJECTORY

TIME (SEC)	MACH	Q (PSF)	ALPHA (DEG)	HEAT (B/SF)	HT RT (B/SF/S)	REYNLD NO
6603.7	1.62	35.7	60.0	38609.8	.3	137677.2
6611.7	1.42	34.3	60.0	38612.0	.2	153160.7
6619.7	1.25	33.0	60.0	38613.5	.2	171345.6
6627.7	1.10	32.1	60.0	38614.7	.1	191938.6
6635.7	.98	31.4	60.0	38615.5	.1	215557.4
6643.7	.87	31.1	60.0	38616.2	.1	243454.2
6651.7	.78	31.0	60.0	38616.7	.1	275549.1
6659.7	.70	30.9	60.0	38617.1	.0	311170.8
6667.7	.63	30.7	60.0	38617.4	.0	349328.2
6675.7	.57	30.5	60.0	38617.6	.0	388993.9
6683.7	.52	30.1	60.0	38617.8	.0	429383.5
6691.7	.48	29.7	60.0	38618.0	.0	471969.2
6699.7	.44	29.2	60.0	38618.1	.0	504606.9
6707.7	.41	28.7	60.0	38618.2	.0	533581.8
6710.4	.40	28.6	60.0	38618.2	.0	542470.2

SECTION VI

APPENDIX B

WESTERN U.S. LAUNCH SITES

FOR THE

HEAVY LIFT LAUNCH VEHICLE

WESTERN U.S. LAUNCH SITES

The HLLV as conceptualized in previous SSPS studies is a high-traffic vehicle of large size. It may be presumed that it will have dedicated launch and landing facilities, and that operations will be routine, in the sense of commercial airline activities, rather than by special and intensive efforts such as marked the Saturn/Apollo launches. The selection, design, and scope of equipment of the HLLV launch site will be large drivers on the design weight and cost of operations of the HLLV, as shown by the following table from data prepared by EX4:

Launch Site	Launch Site Latitude, Deg	Launch Elev., Ft	Gross Payload, Lbs	OMPS, Lbs	Net Payload, Lbs	Payload Change, Lbs
South America	5.50	0	1,051,390	51,390	1,000,000	0
ETR	28.608	0	1,016,315	49,675	966,640	-33,360
Arizona	32.30	6,000	1,034,487	50,564	983,923	-16,077

In short, moving the launch site north requires a vehicle or payload weight penalty for orbital maneuvering propellant; locating the launch site at high elevations saves main-stage propellant and vehicle weight. The most desirable launch site is thus at the highest feasible altitude at the point closest to the equator. Within the Continental United States, this combination occurs in the Southwest from West Texas to Arizona and Nevada. Advantages and disadvantages of a Southwest U.S. launch site are summarized below:

Advantages: Climate - is characterized by rain falls of 6 to 10 inches per year. Operations are seldom constrained by adverse weather; military and commercial airport operations are conducted under VFR rules 95-99% of the year. There are no hurricanes or other large-scale tropical storms. Corrosion is minimal, and preventive maintenance costs on facilities and ground equipment are in the range of 10-20% of these for equivalent items at a seacoast launch site. Savings in corrosion control requirements on the HLLV may be in the order of one to two percent of vehicle weight for equivalent vehicle lifetimes.

Direct Costs - payroll costs are based upon prevailing U.S. payrolls; and field-station bonuses and overseas pay differentials are avoided. Transportation costs are nominal, and payloads may be shipped directly by rail, avoiding trans-shipment and handling costs and delays. Money remains in the U.S.

Indirect Costs - Existing communities can provide support of their local economy (e.g., homes, hospitals, medical care, groceries, highways, recreational and entertainment facilities); whereas, an island launch site, such as Kwajalein, requires about as many indirect personnel as direct (e.g., BX/s, or PX's, field hospitals, recreation centers, etc.). Total costs for an island launch site are about double those of a conus site.

Operational Advantages: An inland site has potential alternate landing sites available for returning orbiter vehicles.

Disadvantages:

Operations: Launch opportunities are limited, in comparison with a near-equatorial launch site. Launch and landing operations impose sonic-boom and launch noise overpressures on a broad footprint.

Safety: Given the number of flights, the probability of a catastrophic failure during launch approaches 1.0, and a debris corridor must be provided.

This report examines some of the cost factors for an inland, Southwestern U.S. launch site, which can be used in examining the cost tradeoffs between launch sites.

Throughout this study, data for launch rates was taken from JSC-11568, Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts, using the program model for "Truss in LEO;" vehicle configuration and performance data was taken from EDIN EX-338-76 when it became available.

HLLV SITE SELECTION CONSIDERATIONS

At the commencement of this study, at the suggestion of Mr. H. P. Davis, JSC Future Programs Office, a nominal launch and landing profile was selected which consisted of a due-East launch, a booster stage landing 200 miles down-range, and an orbiter landing using the same landing field after return from orbit. While this mission profile is simplistic, it provided a convenient baseline from which to begin the study, and upon which to base comparison between sites. To this profile were added the following assumptions:

a. Launch site buffer zones are sized by:

   (1) Noise impinged by launch on adjacent property owners.

   (2) Explosive hazard limits of launch vehicle propellant load at launch or early boost phase, taken as 10 kiloton high explosive equivalent.

b. Launch debris corridor scaled from WSMR practice for off-range missile tests. High hazard events are at first-stage ignition and lift-off, and at separation and staging.

   (For EDIN EX-338-76, separation begins at 144,000 feet altitude, 35.9 miles downrange; second-stage ignition occurs at 151,000 feet, 39.7 miles downrange.)

c. Landing area approach zones sized by desire to keep sonic booms of over 8 1 psf limited to areas of low population density (less than one person per square mile).

d. Above criteria developed a "key" shaped zone representing potential land area impacted by HLLV operational characteristics (see figure 1).

e. Since it is desirable to launch at higher altitudes, it was assumed that launch sites could be located in mountainous terrain, and that potential savings in vehicle weight and performance would pay for fairly extensive site development.

f. Since the booster and orbiter are envisioned as fixed-wing craft, it would be desirable to have landing sites at the lowest possible elevations, to minimize the size of wing required for nominal landing speeds.

g. While NASA need not own all the land shown in the "key," it would be desirable for the Agency to own the land at

HLLV LAND USE ASSUMPTIONS

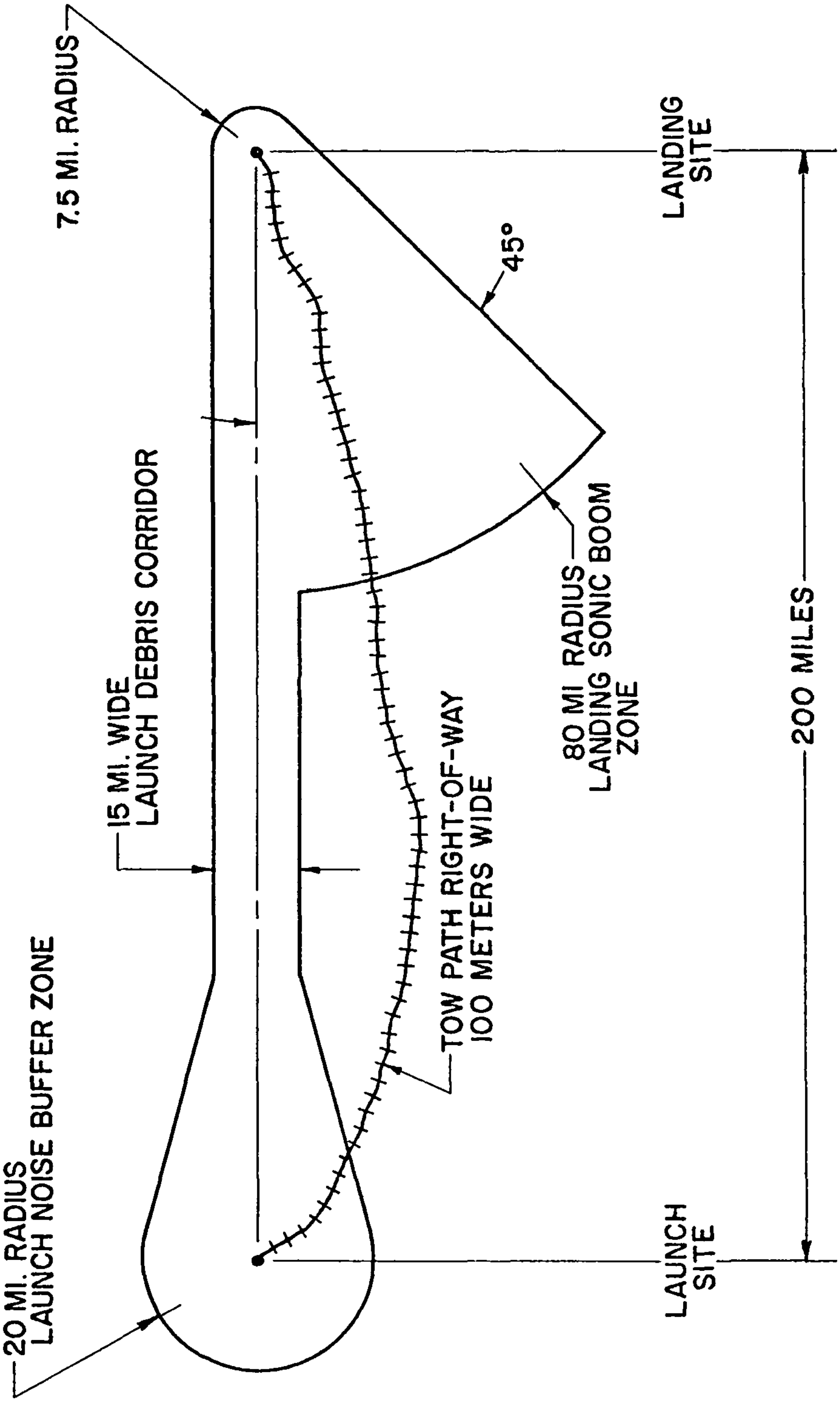


Figure 1

the launch site, the landing site, and the actual right-of-way of the tow path returning the launch vehicles from the landing site to the launch site. Ideally, this land should be in the public domain, already owned by the Bureau of Land Management, DoD, U.S. Forest Service, etc.

h. Land in the launch debris corridor, approach zone, and hazard zone surrounding the launch site need not be owned by the NASA, but should be restricted from development, by interagency agreements, BLM protective withdrawals, purchase of development rights, etc.

i. Use of Indian lands should be avoided, if possible, since changes of treaty lands would require Congressional approval.

From these assumptions, and from study of 1:100,000 scale aeronautical maps, seven sites were selected for further study. (See Figure 2). Additional maps (scale 1:250,000) were obtained from the U.S. Army Map Service, and land use maps (scale 1:500,000) were obtained from the Bureau of Land Management for the states of New Mexico, Arizona, and Nevada. (Texas land is almost universally private or state-owned, under the terms by which Texas entered the union.)

In the course of further study, one of the tentatively-selected sites was found to offer no compelling advantages (Indian Springs, NV) and several compelling disadvantages, among them a high population density in the Lake Meade Recreational Area and very adverse terrain for the landing site, lying north of the Grand Canyon. This site was dropped from further study.

The following tables indicated our findings on the launch sites.

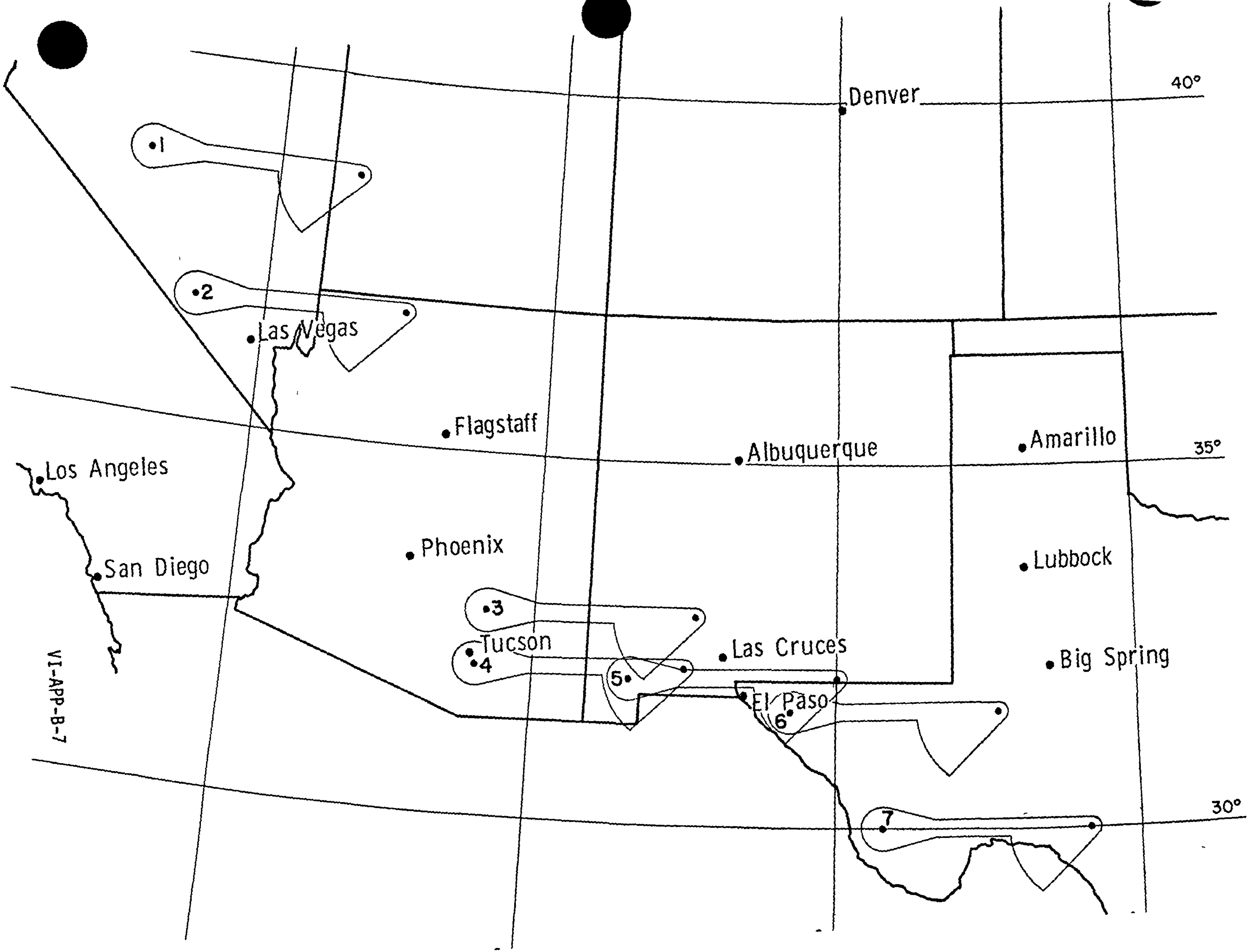

40°
35°
30°
Denver
Amarillo
Albuquerque
Flagstaff
Las Vegas
Los Angeles
San Diego
Phoenix
Tucson
Las Cruces
El Paso
Lubbock
Big Spring
1
2
3
4
5
6
7

TABLE I

Locations of HLLV Launch and Landing Sites

Short Name	Latitude	Launch Site Long. Long/Elev/Map*	Landing Site Long. Long/Elev/Map
1. Monitor Range, NV	38°50'	116°55'/10,000'+/NJ11-5	113°10'/4519'/NJ12-4
2. Indian Springs, NV	------------	DELETED FROM FURTHER STUDY	----------------------
3. Table Mountain, AZ	32°55'	110°30'/6000'/NI12-11	106°25'/4050'/NH13-10
4. Whetstone Mtns, AZ	31°45'	110°25'/6000'/NH12-2	106°50'/4200'/NH13-1
5. Animas, NM	32°10'	108°40'/5600'/NH12-3	105°10'/3650'/NH13-2
6. Hueco Range, TX	31°50'	105°50'/5600'/NH13-1	102°30'/3090'/NH13-3
7. Chinati Peak, TX	29°55'	104°25'/7000'/NH13-8	101°10'/1800'/NH14-7

* Map designation is for U.S. Army Map Service 1:250,000 series.

TABLE II

HLLV LAUNCH AND LANDING SITES

Short Name	Launch Site	Landing Site	Tow Path
1. Monitor Range, NV	50 miles NE of Tonopah, in Monitor Mountains. Access via St. Hwy 82	Sevier Dry Lake, Utah, 30 miles N. of Milford. Access via US 6, 50	Mostly Parallel to US 6
2. Indian Springs, NV	Indian Springs AFB	North Rim, Grand Canyon	---------
3. Table Mountain, AZ	40 miles NE of Tucson	Northrup Strip, WSMR Dry Lake Bed	Mostly parallel to active southern Pacific Track
4. Whetstone Mountain, (was Apache Peak), AZ	40 miles SSE of Tucson	South of Kilbourne Hole, 20 miles due south of Las Cruces, NM	Abondoned Southern Pacific RR right-of-way thru Gadsden Purchase area, reversion to U.S. Govt.
5. Animas, NM	Pyramid Mountains, 15-20 miles south of Lordsburg, NM	Salt Flats Dry Lake Beds near Dell City, TX	Ranch Roads to NE of El Paso, abandoned S. P. right of way to launch site
6. Hueco Range, TX	Hueco Mountains, 30 miles ESE of El Paso, TX	20 miles South of Odessa, TX	Parallel to US 80
7. Chinati Peak, TX	Sierra Vieja Mountains 30 miles SW of Marfa, TX	30 miles South of Sonora, TX	Roughly parallel to US 90

TABLE III

HLLV LAUNCH AND LANDING SITES

Short Name	Nearest Metro Area/Distance	Land Use Status	Availability of Support Services
1. Monitor Range, NV	Las Vegas, NV/250 miles to launch sites; Tonopah 50 miles to launch site	Mostly public domain; BLM, U.S.F.S.	No electrical power No gas pipeline No large adjacent community
2. Indian Springs, NV	Las Vegas, NV/80 miles to launch site	Not Studied in Detail	
3. Table Mountain, AZ	Tucson, AZ/40 miles to launch site. El Paso, TX/80 miles to landing site.	Access to launch site mostly private land, undeveloped-landing site on WSMR	15 miles to 115 KVA lines, 15 miles to pipeline
4. Apache Peak, AZ	Tucson, AZ/40 miles to launch site. El Paso, TX/25 miles to landing site	U.S.F.S, private undeveloped land, and BLM	16 miles to 115 KVA and 230 KVA lines, 15 miles to pipeline
5. Animas, NM	El Paso, TX, equidistant between launch and landing sites	Mostly BLM land	10 miles to 115 KVA line, 20 miles to pipeline
6. Hueco Range, TX	El Paso, TX, 25 miles to launch site Odessa, TX, 35 miles to landing site	Private and State Lands, undeveloped	18 miles to 510 MW power plant - 6 miles t pipeline
7. Chinati Peak, TX	San Antonio, TX, 160 miles to landing site	Private and State lands, undeveloped to semi-developed ranching	No electrical power No gas pipeline No large adjacent community

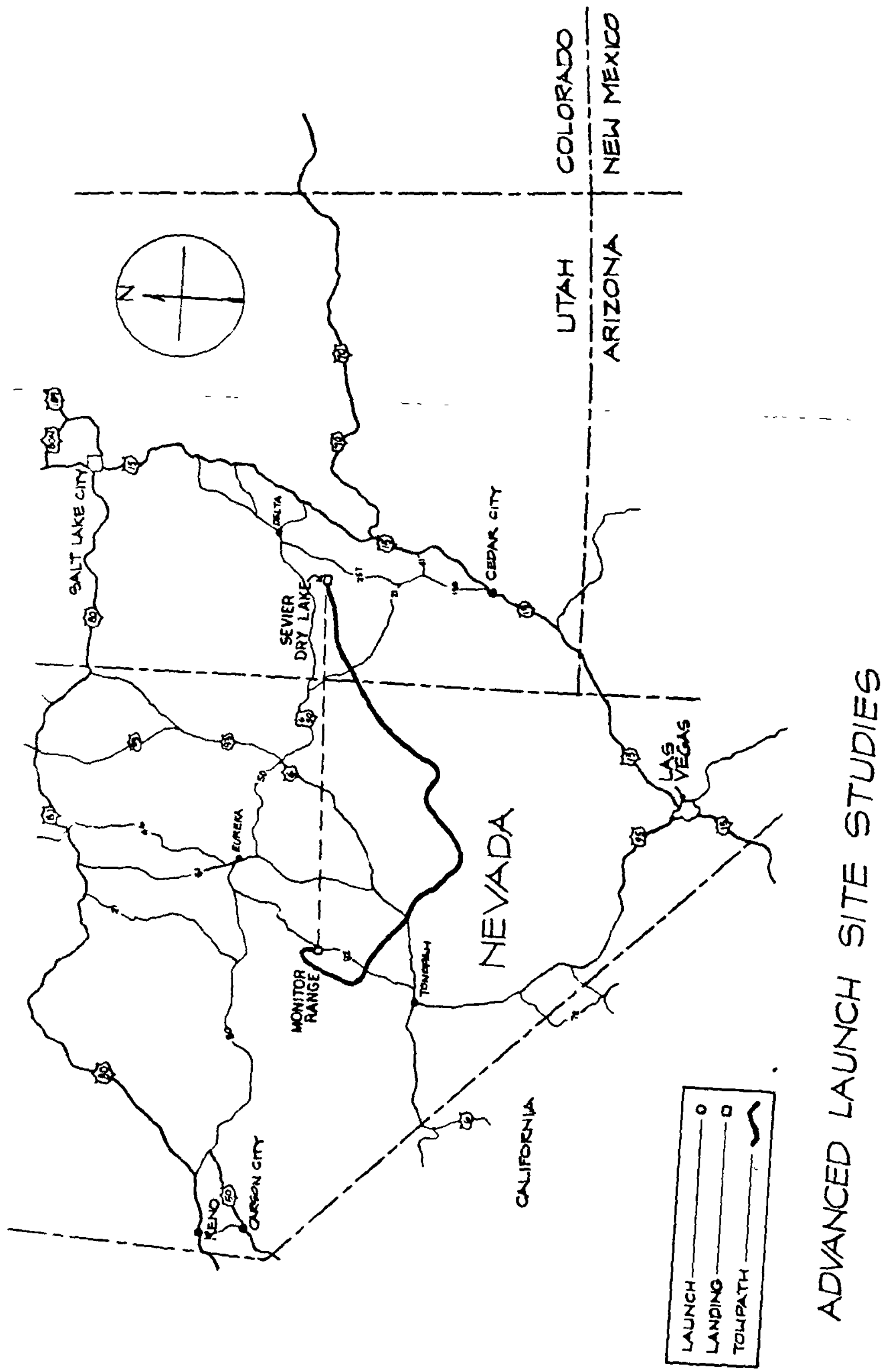
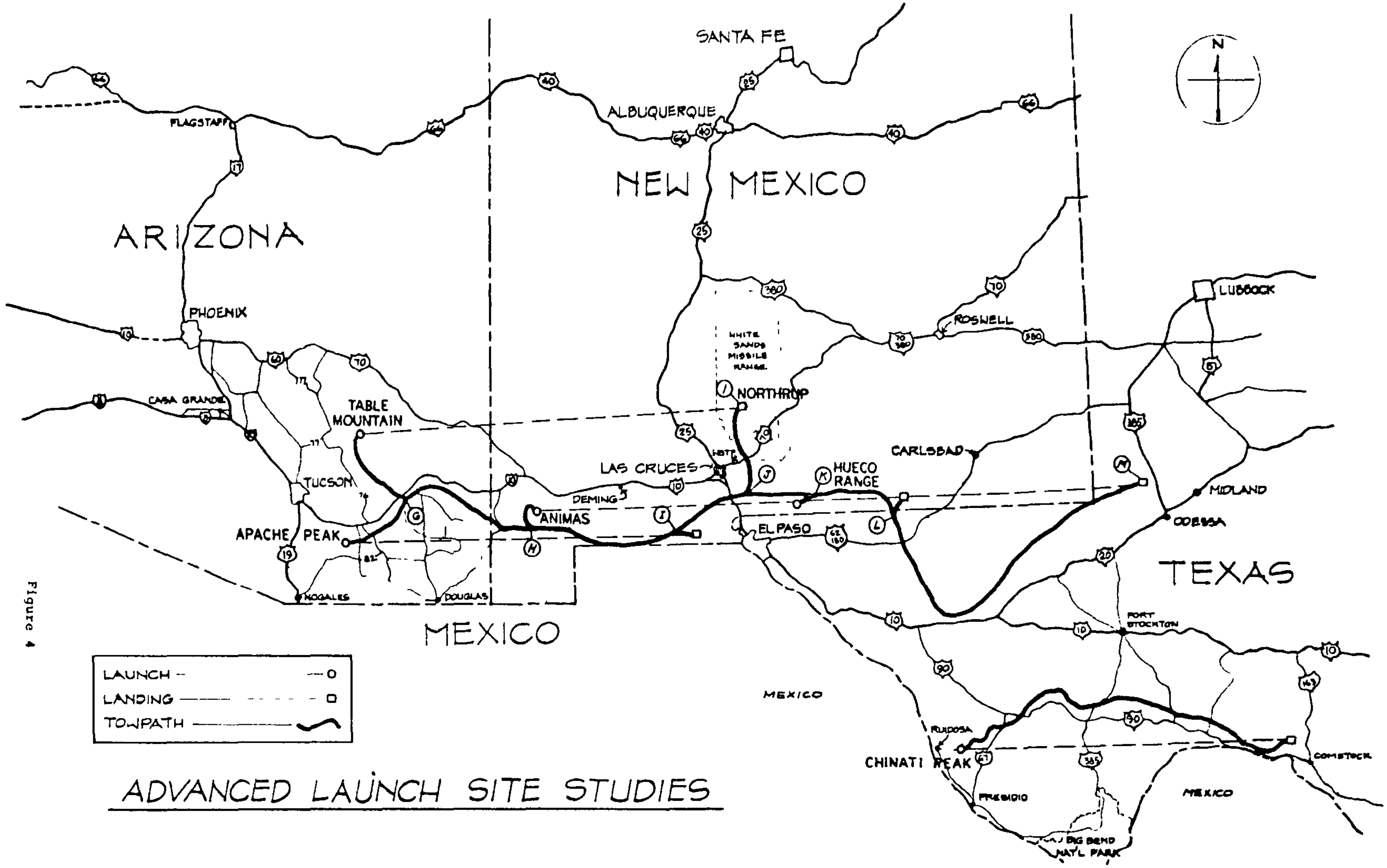

ADVANCED LAUNCH SITE STUDIES
COLORADO
NEW MEXICO
UTAH
ARIZONA
NEVADA
CALIFORNIA
SALT LAKE CITY
DELTA
SEVIER DRY LAKE
CEDAR CITY
LAS VEGAS
EUREKA
MONITOR RANGE
TONOPAH
RENO
CARSON CITY
LAUNCH
LANDING
TOWPATH

Figure 3



N
SANTA FE
ALBUQUERQUE
FLAGSTAFF
NEW MEXICO
ARIZONA
PHOENIX
CASA GRANDE
TABLE MOUNTAIN
TUCSON
APACHE PEAK
NOGALES
DOUGLAS
MEXICO
WHITE SANDS MISSILE RANGE
NORTHRUP
LAS CRUCES
DEMING
ANIMAS
EL PASO
HUECO RANGE
CARLSBAD
ROSWELL
LUBBOCK
MIDLAND
ODESSA
TEXAS
FORT STOCKTON
RUIDOSA
CHINATI PEAK
PRESIDIO
BIG BEND NAT'L PARK
COMSTOCK
MEXICO
MEXICO
LAUNCH
LANDING
TOWPATH
ADVANCED LAUNCH SITE STUDIES

Figure 4

Cost Comparisons between Launch Sites

To compare relative costs between launch sites, it was assumed that launch pad and landing site construction and site preparation costs would be roughly equal between the various sites. (This was a simplifying assumption only; these costs may vary by a factor of two depending upon the actual terrain selected; but limited study resources did not permit site inspections.) Major differences were assumed to lie in the amount of land to be acquired; land in Federal ownership was assumed to be available to NASA without additional cost. The other significant variable was in the cost of acquisition and construction of the transportation route of the booster and orbiter back to the launch site. Overlays on land status maps provided an approximation of land to be acquired from private ownership, and local realtors provided gross estimates of land values. Launch vehicle transport routes, informally called tow paths, were selected by review of 1:250,000 maps and (from Eastern Arizona to Dell City, Texas) by personal reconnaisance. Table IV displays the findings of these cost studies.

Costs of land acquisition should be taken as figures of merit only, since they were based on broad estimates and land quality is highly variable in the Southwest. The figures for land acquisition in Texas, particularly, are uncertain since the largest unknowns are the amount of state-owned land and the policy of state government officials if an HLLV site were selected in Texas.

Costs of tow-path right-of-way and construction are based upon railroad-type construction practices, rather than highway practices. Pricing was performed using rules of thumb of the Southern Pacific engineering staff, and are probably accurate to within $\pm$ 30%.

Costs of providing utilities to the launch area were derived from estimating data provided by El Paso Electric Company and El Paso Natural Gas Company engineers.

If longer booster flights are required, there exist a number of potential launch-landing site pairs along Latitude 32°. Table V displays tow-path costs between the letter-designated points shown in the previous figure.

TABLE IV

COST DIFFERENTIALS OF HLLV LAUNCH AND LANDING SITES

Short Name	Land Acquisition				Tow Path	
	Purchase Sq. Mi.	Costs	Restr. Lease, Sq. Mi.	Costs	Tow Path Acq'n & Constr Costs	Costs of Energy Utilities to Launch Area
1. Monitor Range, NV	0	0	120	$65M	339.8 miles-168.8M	20-30 M
2. Indian Springs, NV	NOT DEVELOPED					
3. Table Mountain, AZ	310	$40M	900	$430M	365.9 miles-187.0M	8 M
4. Whetstone Mtn, AZ	125	$16M	440	$210M	235.4 miles-124.7M	4 M
5. Animas, NM	95	$12M	110	$54M	252.8 miles-113.03M	4 M
6. Hueco Range, TX	220	$62M	3,000	$1200M	265.9 miles-120.5M	7 M
7. Chinati Peak, TX	390	$90M	4,400	$1400M	251.3 miles-132.2M	20-30 M

TABLE V

TOW PATH COSTS, POINT-TO-POINT (Figure 4)

Points	Length	Cost
G-H	79.7 miles	$41.2M
H-I	107.3 miles	$51.4M
I-J	37.8 miles	$21.4M
J-K	46.0 miles	$19.3M
K-L	43.5 miles	$17.4M
L-M	211.2 miles	$101.6M

Selection of Candidate Site

No specific site recommendation is made, based upon this survey-level study, since refinements in vehicle design, launch azimuth optimization, and launch-to-landing site distances, would rapidly supersede any of these study findings. However, to examine other cost and design aspects, a launch site in the Pyramid Mountains near Animas, New Mexico, and a landing site near Dell City, Texas, were postulated, and tentative site facilities and operational time lines were developed around this site. (The considerations discussed below would not, however, change significantly from site to site for the Table Mountain, Whetstone Mountain, or Hueco Range sites, since their configurations would be similar to the Pyramid site.)

For the site concept selected, the Industrial Area was located midway between the launch and landing sites, since the largest number of the HLLV operations team will operate in that area, and local transportation and homes, businesses, and other elements of the supporting economy are available without cost to the program.

Preliminary concept sketches were prepared to sharpen our understanding of the design and operational problems, and a preliminary operations timeline was postulated as a method of sizing work crews, quantity of equipment, number of vehicle assembly bays, etc. (The first sketches were made before EDIN EX -338-76 became available to us, and are included only to show our general approaches.) The design and cost drivers identified for the HLLV ground facilities are listed below:

Launch Area:

Design drivers - high "production" launch rate (10-12 per day)

- probability of catastrophic failure at launch, over life of program (35,000 launches) approaches 1.0.

Consequences

- permanent party at launch area should be kept small, and LV handling, erection, loading, and checkout should be highly automated.
- launch crew should be "vehicle-oriented," should come to the launch site with the vehicle, and be capable of erecting, loading, and launching in one working shift.

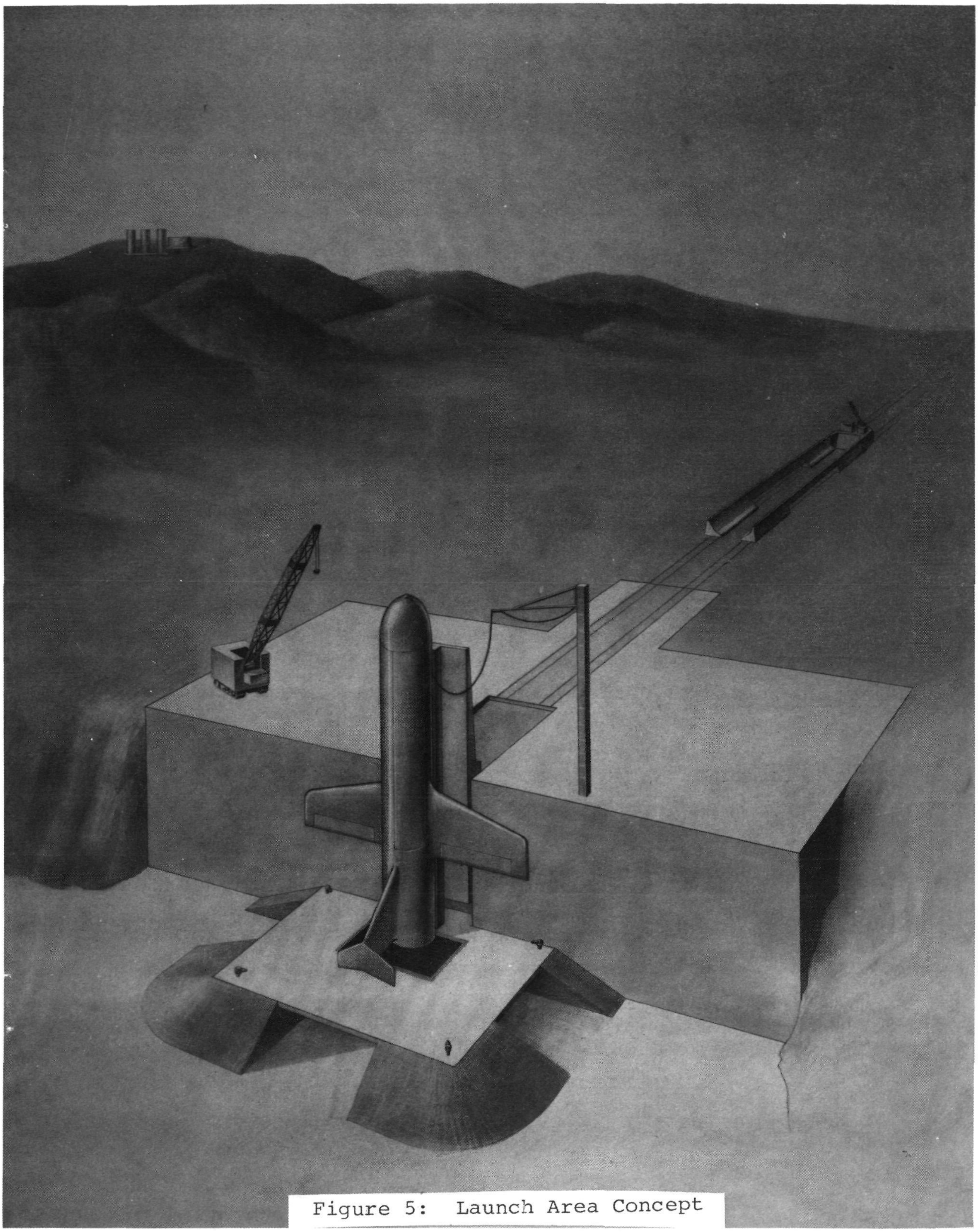


Figure 5: Launch Area Concept

- launch vehicle repairs (except very minor repairs, e.g., quick changes of LRU's) should be performed at the Industrial Area, even if this involves returning the LV from the launcher to the I.A.

- erection procedures should be simple, with tilt-tables or other positive vehicle handling, rather than by cranes, hoists, slings, and dangling loads.

- if line sizes and loading times permit, propellant loading should be by gravity feed rather than pump feed, to avoid propellant pump failures impacting launch schedules.

- launch sites may be located on or near mountain tops, requiring steep grades for the launch vehicle transporter. A design/cost study of alternatives for achieving these higher-altitude sites (e.g., comparison of cog-wheel railroads, cable-assisted systems, etc.) should be performed.

<u>Landing Site:</u>

<u>Design Driver</u> - number of launches per launch window may require "ripple-firing" of HLLV's

<u>Consequences</u> - GSE should be available to move LV's from runway in three to five minutes, at least to dispersal (parking) areas.

- permanent party at landing site is small; receiving and servicing team meets launch vehicle at landing site, loads on transporter, and performs post-flight checkout on transporter during trip back to Industrial Area.

- launch vehicle deservicing (draining, purging, etc.) must be kept to a minimum, if vehicle turn-around times are to be achieved. Best practice would appear to be no deservicing except when LV's are scheduled for overhaul.

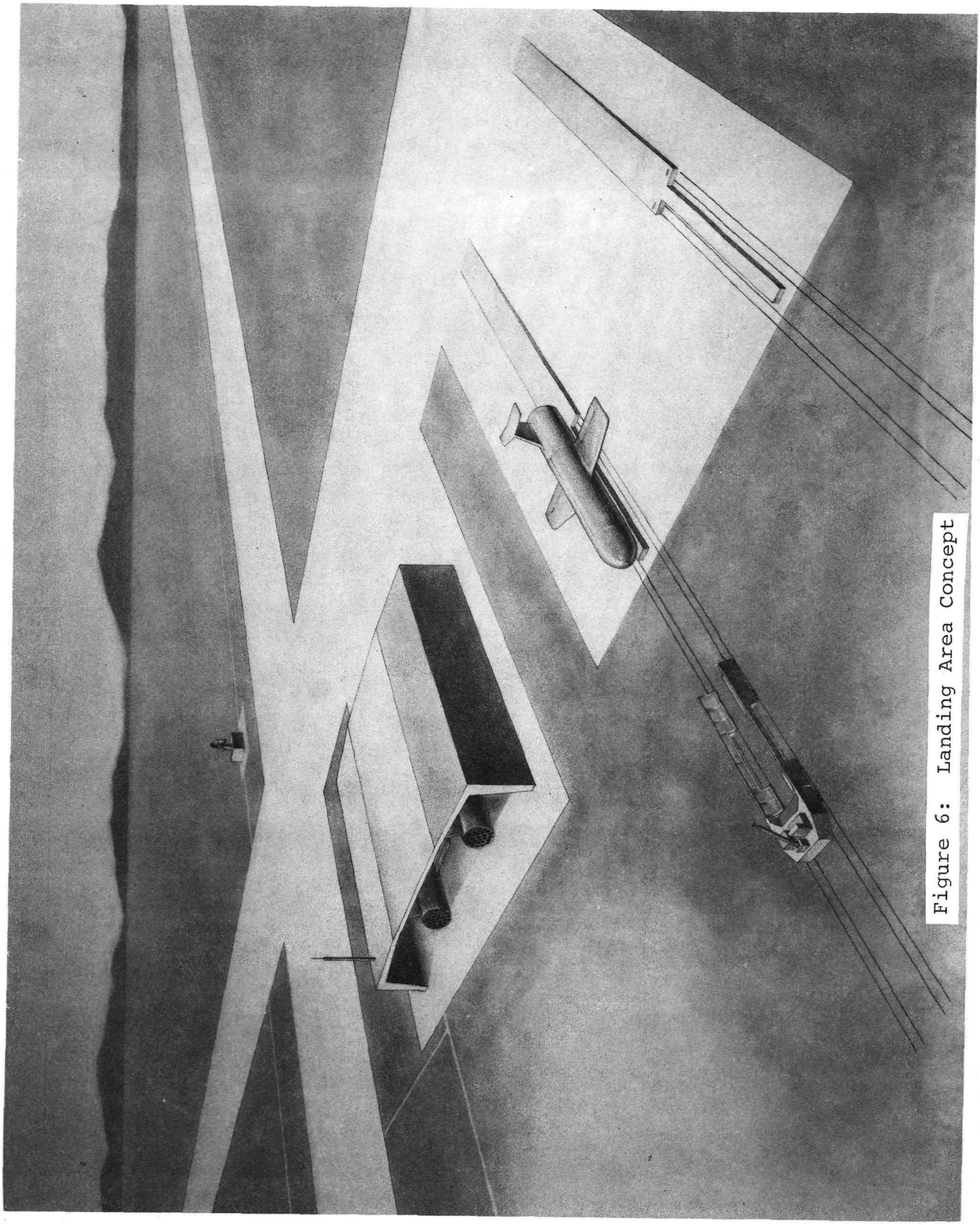


Figure 6: Landing Area Concept

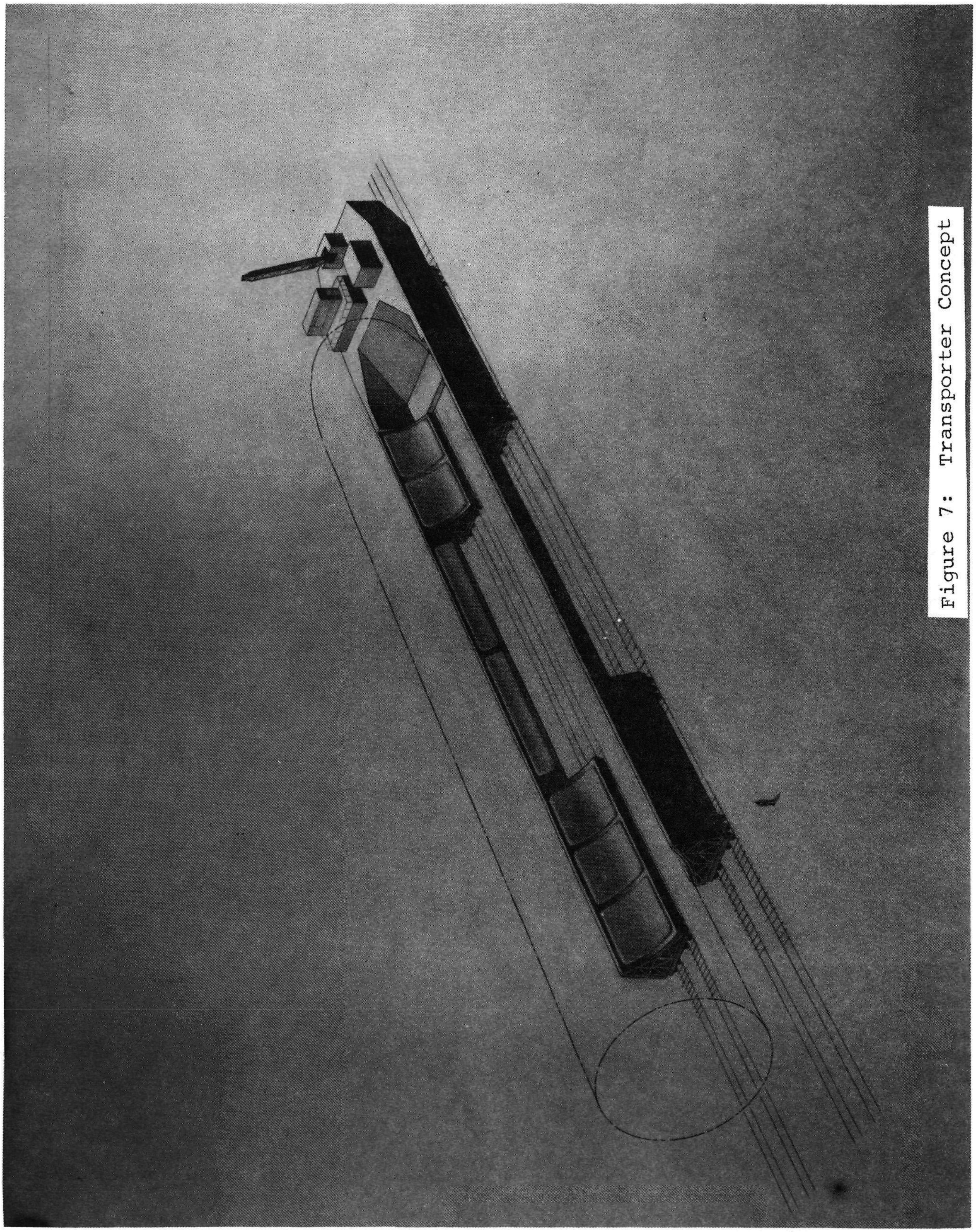


Figure 7: Transporter Concept

Transporters:

Design Concepts - Following airline practice, it may be desirable to keep the launch vehicle electrical systems powered-on at all times. Transporters will furnish this power when vehicle is switched from internal to external power.

- LV's will be on transporters except when they are on the launch pad or in flight. Checkout of LV's should be done by a "Mobile ACE" station on each transporter. (In this concept, boosters would not be tied to second stages, but could return immediately to the launch site, to meet a new second stage, unless major rework or refurb were required.)

- transporter should have a small maintenance shop aboard, as well as crew rest quarters, galley, etc., since trip times from landing site to launch site may be 12 hours or more in duration.

- drive-train of the transporter should be propane-fueled, to simplify logistics. Either a diesel-electric or turbine-electric drive would be suitable. Cog-wheel gearing and an alternate low-speed, high-gear ratio drive train will provide for moving transporter up and down steep grades at launch site, and positive control at creep speeds at the landing site and in the industrial area.

- transporters are envisioned as interchangeable between booster and second stage vehicles with only minor kit changes. Vehicles are supported on the transporter by inflated air bags, to avoid alignment problems and provide a cushioned ride.

Tow Path

Design Concepts - Interstate highway construction was compared with rail construction as follows:

1976 costs	4-lane Interstate	$1.2M/mile
(right of way, grading, draining, cut and fill)		$0.6M/mile
(Ballast and pavement)		$0.6M/mile

	1976 Cost	6-lane Interstate	$1.65M/mile
	1976 Cost	Railroad, single track, two-rail construction, using new 119# rail, including rails, ties, ballast ($33/foot)	$175,000/mile
		Cost of double track with cuts, fills, right of way, draining, ties, ballast, and rail	$950,000/mile

(Very Large Array Radio Telescope near Socorro, New Mexico, performed equivalent analysis and is using rail.)

Industrial Area:

Design Drivers - HLLV's are probably too large to build elsewhere and transport to launch operations area, and therefore final assembly facilities should be at the launch center Industrial Area.

- Payloads, as assembled, will also be too large for conventional transportation and payload assembly should similarly be performed at the launch center Industrial Area.
- Production rate of HLLV's should be reexamined since rate as shown in JSC-11568 will require a large number of vehicle assembly bays.
- Number of assembly/refurbishment bays is also dependent upon reuse and refurbishment rates of LV's, and time required for overhaul.

Final concept shown, following railroad round-house and turntable technology, assumes that production rate of LV's is fairly constant, and that assembly bays can also be used for launch vehicle refurbishment.

Launch Center Construction:

A preliminary construction phasing for the launch center facilities was developed as follows:

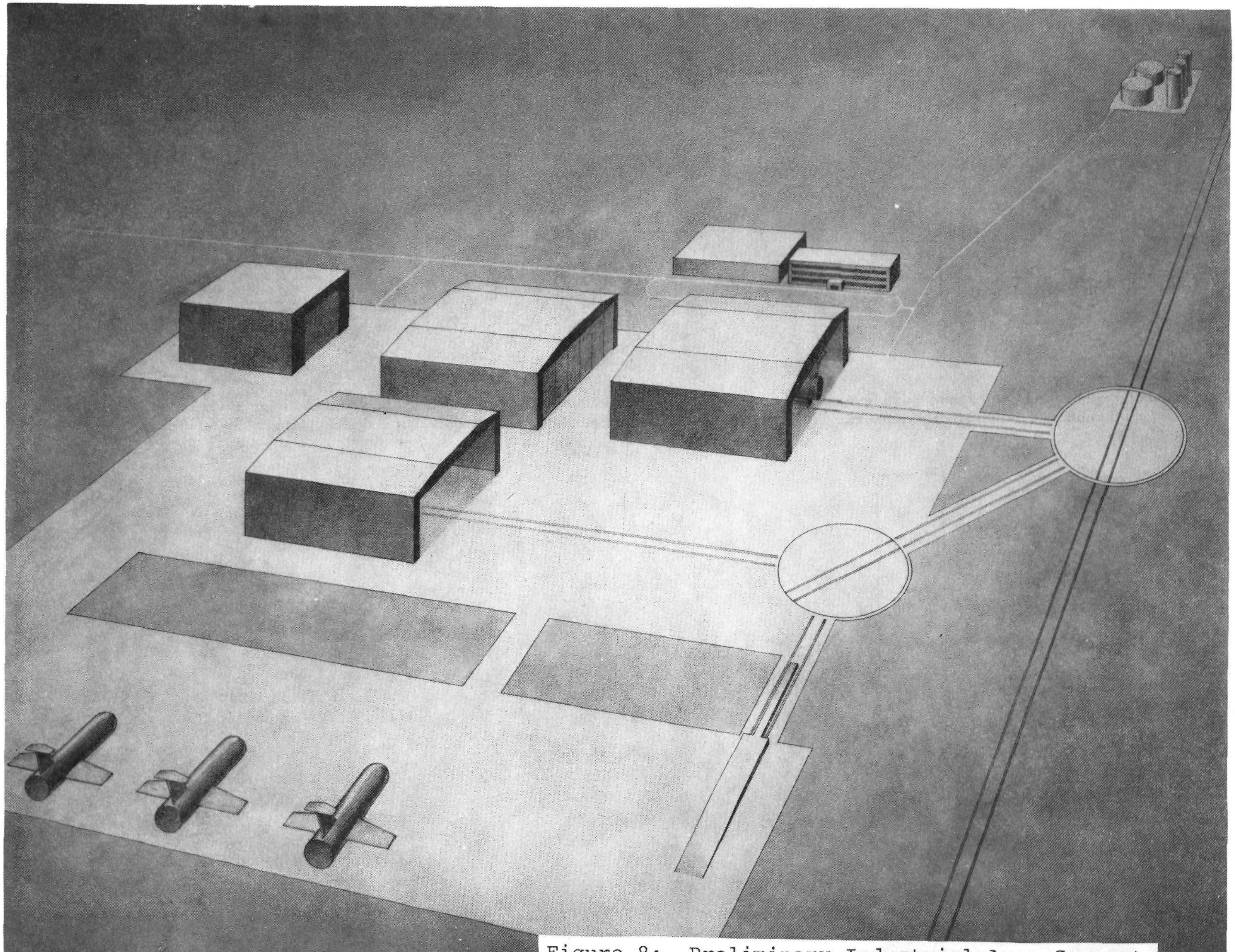


Figure 8: Preliminary Industrial Area Concept

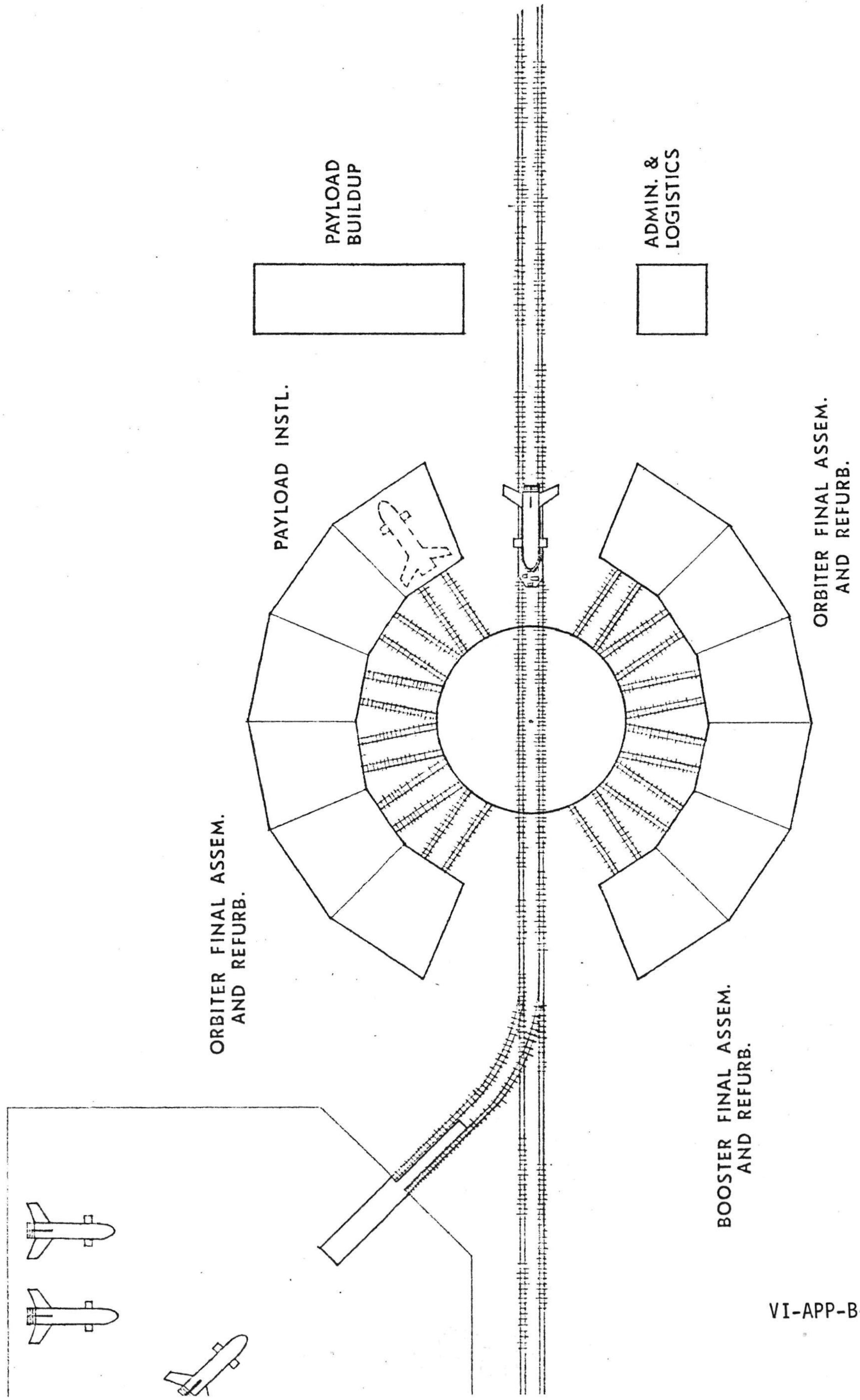
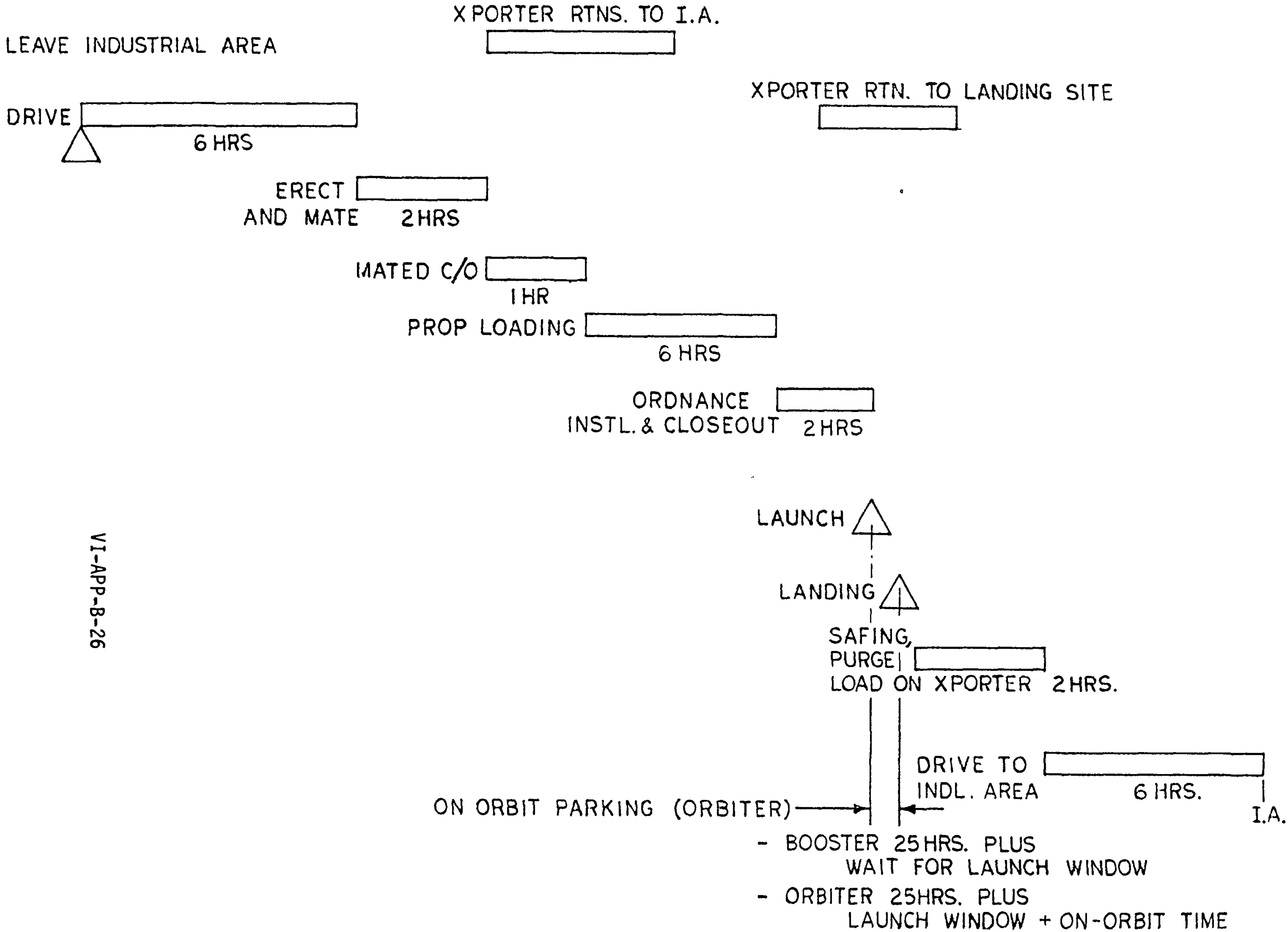

PAYLOAD BUILDUP
ADMIN. & LOGISTICS
PAYLOAD INSTL.
ORBITER FINAL ASSEM. AND REFURB.
ORBITER FINAL ASSEM. AND REFURB.
BOOSTER FINAL ASSEM. AND REFURB.

Figure 9

TABLE VI

Initial Construction	Est. Costs (1977 $ in M)	
Three launch pads ($120M each)	360	
Propellant Tank Farm	150	
Landing Area	70	
Towpath	140	
Propane Pipeline and Pumping System	200	
Lox Plant, Part I	40	
Six Final Assembly/Refurbishment Bays	40	
Payload Buildup Building	20	
Admin/Logistics Building	5	
Launch/Vehicle Parking Pad	1	
Launch/Range Control	90	
10 Transporters	90	
		1206
Third Year Construction		
Rectenna and Power Distribution	100	
Hydrogen/Electrolysis Plant, Part I	40	
Three Launch Pads	360	
Expand Propellant Tank Farm	150	
10 Additional Transporters	90	
		740
Tenth Year Construction		
Six Additional Final Assembly/Refurbishment Bays	40	
Six Additional Launch Pads	720	
Expand Propellant Tank Farm	200	
Lox Plant, Part II	40	
Hydrogen Plant, Part II	60	
40 Additional Transporters	360	
		1420
Total Estimated Cost of Facilities, 1977		$3366M



LEAVE INDUSTRIAL AREA
DRIVE
6 HRS
XPORTER RTNS. TO I.A.
ERECT
AND MATE
2HRS
MATED C/O
1 HR
PROP LOADING
6 HRS
ORDNANCE
INSTL. & CLOSEOUT
2 HRS
XPORTER RTN. TO LANDING SITE
LAUNCH
LANDING
SAFING,
PURGE
LOAD ON XPORTER
2 HRS.
DRIVE TO
INDL. AREA
6 HRS.
I.A.
ON ORBIT PARKING (ORBITER)
- BOOSTER 25 HRS. PLUS
WAIT FOR LAUNCH WINDOW
- ORBITER 25 HRS. PLUS
LAUNCH WINDOW + ON-ORBIT TIME

STAFFING

A preliminary estimate of the staffing required for HLLV operations has been made, based upon the following assumptions:

- final assembly of the launch vehicle is performed at the launch complex industrial area, but other manufacturing operations are performed elsewhere.

- payloads are assembled, integrated, and loaded into payload units at the industrial area, but are manufactured elsewhere.

- all HLLV operations are conducted on a three-shift, seven-day work week, since the cost is small in comparison with the cost of maintaining the on-orbit work crews in space.

Final Assembly crews were based upon present Shuttle final assembly crews at Palmdale (36 engineers, 258 technicians, and 40 supporting personnel) and Dryden (12 engineers, 184 technicians).

Launch crews were based on a 'core-team' concept, with a core group of 4 engineers, 16 technicians, and 8 support personnel per vehicle per shift. To maintain twentyfour-hour operation, the core team, per vehicle in the operations pipeline, was estimated as 16 engineers, 64 technicians, and 16 support. To this core team were added trainees, backups for sickness and annual leave.

Landing crews were also based on the core-team concept, with a core group of 4 engineers, 12 technicians, and 2 support personnel per vehicle, per shift.

Refurbishment crews were estimated as a fraction of the final assembly crews. Since no experience from Shuttle is available, these estimates must be regarded as soft.

Payload buildup crews were matched to payload launch schedules. A learning curve was applied to their productivity, so that there are signficantly fewer personnel/payload in the years of peak activity. This estimate is also 'soft'.

Peak staffing occurs in the twentyseventh year of HLLV activity, peaking at about 1500 engineers, 5300 technicians, and 1200 support personnel. Total staffing was:

Engr'g-38,830 manyears, at$1.55 Billion,
Tech'n-122,110 manyears, at 3.05 Billion
Sup't - 30,900 manyears, at .93 Billion
$5.53 Billion, 1977 dollars.

This staffing was based on achieving the launch rates for the Truss SSPS in LEO.

The following table displays the staffing, by function, for each year, starting with a year Zero indicating the size of the site activation team.

HLLV STAFFING (TRUSS IN LEO)

Year	Final Assembly			Launch OPNS			Landing OPNS			Refurb OPNS			Payload Buildup			TOTALS			
	Engr's	Techn's	Supt	Engr's	Tech'ns	Supt	Engr's	Techn's	Supt	Engr's	Techn's	Supt	Engr's	Techn's	Supt	Engr's	Techn's	Supt	
0	100	900	150	600	1800	300	100	200	20	0	0	0	200	600	200	1000	3500	670	[illegible]
1	60	600	100	100	600	300	20	50	10	40	300	50	500	900	220	720	2450	680	[illegible]
2	60	600	100	65	250	120	20	50	10	50	320	50	500	900	220	695	2120	500	[illegible]
3	60	600	100	65	250	120	40	100	20	60	350	50	550	1000	240	795	2200	530	
4	60	600	100	65	250	120	40	100	20	60	350	50	600	1000	260	825	2200	550	[illegible]
5	60	600	100	65	250	120	40	100	20	60	350	50	600	1100	260	825	2300	550	[illegible]
6	60	600	100	65	250	120	40	100	20	60	350	50	650	1150	280	875	2350	570	[illegible]
7	60	600	100	120	480	240 *	60	150	30	60	350	50	700	1200	300	1000	2730	720	[illegible]
8	60	600	100	90	360	270	60	150	30	60	350	50	700	1250	300	970	2710	750	[illegible]
9	60	600	100	90	360	270	60	150	30	60	350	50	700	1300	350	970	2760	800	[illegible]
10	60	600	100	90	360	270	60	150	30	60	350	50	750	1350	350	1020	2810	800	[illegible]
11	60	600	100	90	360	270	90	240	45	60	350	50	750	1400	350	1050	2950	815	
12	90	900	150 *	150	600	300 *	90	240	45	60	350	50	800	1450	350	1190	3540	895	
13	90	1200	150	120	480	240	90	240	45	60	350	50	800	1500	400	1160	3770	885	[illegible]
14	60	900	150	120	480	240	90	240	45	90	650	100	850	1600	480	1210	3570	935	[illegible]
15	60	900	150	120	480	240	120	300	60	90	650	100	850	1600	400	1240	3930	950	
16	90	900	150	160	640	320 *	120	300	60	90	650	100	900	1700	400	1360	4490	1030	[illegible]
17	90	1200	150	160	640	320	120	300	60	90	650	100	900	1700	430	1360	4490	1060	[illegible]
18	60	900	150	160	640	320	120	300	60	120	650	100	950	1800	430	1390	4290	1060	[illegible]
19	60	900	150	160	640	320	120	300	60	120	650	100	950	1900	460	1380	4390	1090	
20	90	1200	150	160	640	320	120	300	60	120	650	100	950	1900	460	1410	4690	1090	[illegible]
21	90	1200	150	160	640	320	120	300	60	120	650	100	1000	2000	500	1460	4790	1130	[illegible]
22	60	900	150	160	640	320	140	400	70	120	950	150	1000	2000	500	1480	4890	1190	[illegible]
23	60	900	150	160	640	320	140	400	70	120	950	150	1000	2000	500	1480	4890	1190	[illegible]
24	60	900	150	160	640	320	140	400	70	120	950	150	1000	2000	500	1480	4890	1190	[illegible]
25	60	1200	150	160	640	320	140	400	70	120	950	150	1000	2000	500	1480	5190	1190	[illegible]
26	60	1200	150	160	640	320	140	400	70	120	950	150	1000	2000	500	1480	5190	1190	[illegible]
27	60	1200	150	160	640	320	160	500	80	120	950	150	1000	2000	500	1500	5290	1200	[illegible]
28	60	900	150	160	640	320	160	500	80	120	950	150	1000	2000	500	1500	4990	1200	[illegible]
29	0	0	0	160	640	320	160	500	80	120	950	150	1000	2000	500	1440	4090	1050	[illegible]
30	0	0	0	130	600	300	130	450	60	120	950	150	1000	2000	500	1380	4000	1010	[illegible]
31	0	0	0	30	120	60	20	50	10	60	300	50	125	250	60	235	720	180	[illegible]
																37,350	117,220	[illegible]	[illegible]
																$1\ 55 \times 10^9$	3 05	93	$\$\ 5\ 53 \times 10^9$

* New Launch Sites

PROPELLANTS

Propellant supplies for the HLLV will be of such scope that dedicated production plants and systems will be desirable. A survey of availability of propellants in this area did not reveal any major problems except for sources of hydrogen.

a. Propane: Propane appears to be one of the few fuels that that will be reasonably available in the 1990 time frame on the world market. A local LP gas distributor who serves on the Board of Directors of the national LP gas distributors association reports that the association anticipates that there will be no major world shortage of this fuel in the next decade. Probable sources will be from production in the Middle East. Estimated prices for propane on the current world market are: Algeria, 24¢/gallon; Saudi Arabia, 36¢/gallon, Venezuala, 20¢/gallon. An average world price of $115 per metric ton may be used as a baseline present price. Chemical and Engineering News predicts an average U.S. price, in 1985, of 31.1¢/gallon (C&EN, 18 April 1977) as compared with a present price of 13.8¢/gallon. Propane, butane, and natural gas are still being flared in most locations in the Middle East for lack of a market.

Propane may, however, find an alternate use as existing natural gas supplies are depleted; plans to supply a propane/ air mixture in existing natural gas markets are being studied.

At present, New Mexico produces about 600 million gallons, and consumes 100 million gallons, yearly. Total U.S. Production in 1974 for propane was 12,347 million gallons, down 6% from the peak 1973 production of 13,100 million gallons. By comparison, the HLLV (EDIN EX-338-76) will require 850,000 gallons per launch, and in the peak program year (2022, Truss in LEO) 2282 HLLV flights will require 1,920 million gallons. The total flight program will require 30,000 million gallons. In short, HLLV operations will have a significant effect on national supplies of propane.

Commercial suppliers of Propane are already investigating storage of propane in known salt domes in West Texas and Eastern New Mexico. Propane would be brought to terminals in Houston and pumped through existing pipelines to these storage domes.

Propane may also be produced by hydrogenating coal, of which there are ample supplies in New Mexico, Colorado, and West Texas. However, the price of manufactured propane does not appear to be competitive, as predicted, in the 1990 time frame.

If propane is selected as the HLLV booster stage fuel, contractual commitments for this fuel should be made as early in the program as possible.

b. Oxygen: Oxygen is, of course, readily available; its principle cost driver is the energy required for compression and liquifaction. Dedicated production plants for LOX, either GOCO or COCO, should be included in launch site planning.

Since the production of LOX will itself be a major user of energy, it is recommended that locating a ground rectenna at or near the launch site be considered; electrical power from the SSPS can thus be used to bootstrap the deployment of additional SSPS's, and the excess sold to the local power grid. Peak year requirement of LOX (Truss in LEO) for 2282 HLLV flights is 16 million tons.

c. Hydrogen: Present sources of hydrogen depend upon cracking natural gas, propane, or refinery "lights". These will be in continuing high demand during the HLLV program, and may not be available. Hydrogen can also be made by flashing steam against coal; this process is, however, both environmentally "dirty" and expensive. Hydrogen is made in commercial quantities in Canada by reverse electrolysis of water (cf. Consolidated Mining and Smelting, Ltd, Trail, B.C.) because of the ready availability of hydroelectric power. If the launch site includes an SSPS rectenna, electrical power from the system can be used to make hydrogen at the launch site. Requirements for water as a feed stock are not excessive. However, most water presently available in the Southwest is already allocated; in the case of the Rio Grande valley, the existing water supply is presently 110-120% allocated. An existing unallocated source of water, however, is the output of municipal sewage plants, which are of surprisingly high quality since they must meet EPA requirements. For example, the Las Cruces municipal sewage plant (50,000 population) processes 4.5 million gallons per day; if electrolysis produced hydrogen from one-third of this water, there would be available from this source alone 460 million pounds of hydrogen per year. The HLLV will require 750,000 pounds H_2 per launch; at peak launch rate, hydrogen consumption will be in the order of 1,720 million pounds per year.

Production of hydrogen by electrolysis will not be the cheapest method during the HLLV program, but it may be desirable to do so since, again, the SSPS program could be presented as bootstrapping itself rather than causing an additional drain on national energy resources.

OTHER CONSUMABLES

a. Water: As noted, water throughout the Southwest is a carefully managed resource. As soon as a Southwestern launch site is selected, coordinated planning with the appropriate State water agencies should be commenced, to assure that water will be available. Water-conservation practices should be designed into the facilities (e.g., recycled cooling water at the launch pads, LOX compressor cooling, industrial sewage reclamation, etc.)

b. Electricity: Electrical power is readily available at all the candidate launch sites, except the Monitor Mountain site. Electrical power can be routed to launch sites for a cost of $100,000 per mile. A map of the existing and proposed electrical power distribution grid for the Southwestern states was obtained from the Western Systems Coordinating Council (See figure 11).

c. Industrial Fuels: Natural gas and LP gas are the only fuels in use, or available in significant quantities in the Southwest. Coal is mined for electrical production on-site in the Four Corners area, but no commercial distribution exists. Natural gas suppliers (e.g., El Paso Natural Gas) are reluctant to make commitments to new users, since they anticipate significant shortages within the next decade.

If the fuel selected for the HLLV is propane, it is recommended that the launch and industrial areas be designed to use propane as an industrial fuel, and that the vaporization losses from the liquid propane on site be used as the plant boiler feed.

VII. ENVIRONMENTAL FACTORS

A. MICROWAVE TRANSMISSION RECEPTION

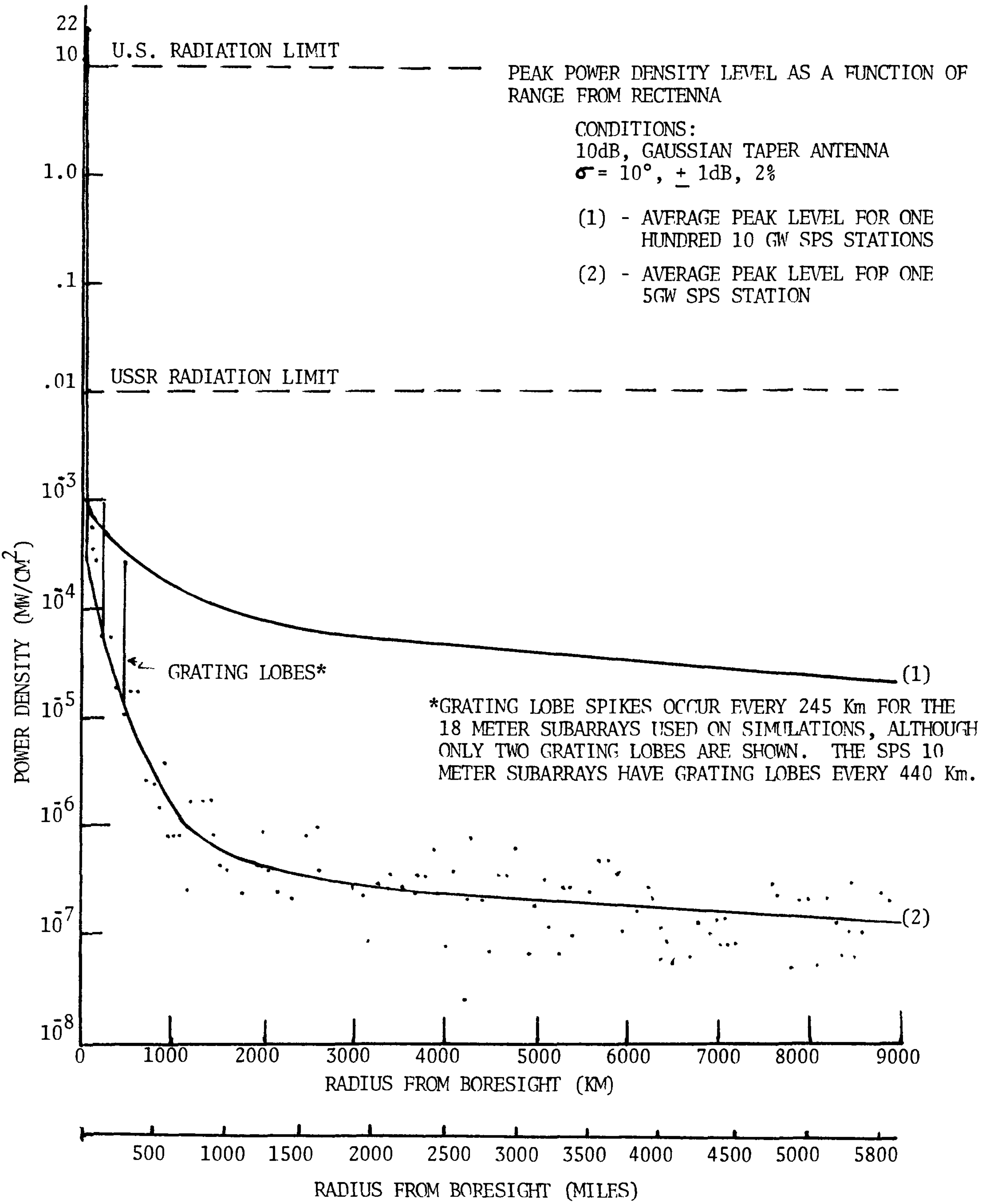
1. Cumulative Side Lobe Effects

The peak power density levels in the far side-lobes of a 5GW SPS system were calculated to ascertain the expected radiation levels over the United States and Europe. Apparently the IMS (industrial medical, and scientific) band of 2450 MHz $\pm$ 50 MHz is recognized only in the United States and certain portions of Europe.

A 5GW, 10db gaussian taper antenna system, with error parameters of $\sigma = 10^0$, $\pm$ 1db, and 2% failures, was used for the analysis. The data given in figure VII.A.1 indicates an average peak level of 2×10^{-7} mw/cm^2 in far fields. Grating lobe spikes will occur every 440Km for the **10** meter by 10 meter subarrays. However in order to reduce computer simulation time, the subarrays were increased to 18 meters thereby producing spikes every 245Km which were 10-12db higher than the surrounding peaks as shown in the figure.

The radiation levels from one hundred, 10GW SPS stations will be approximately 4×10^{-5} mw/cm^2 in the far-fields as shown by curve (1). Since this level is over two orders of magnitude lower than the USSR radiation standard of .01 mw/cm^2 and five orders of magnitude lower than the present US standard, there should not be a problem in radiating with the 2400-2500 MHz power beams.

Figure VII.A-1. -Far-Field Radiation Levels for Individual and Multiple SPS Stations



VII. A.2 Ionospheric Tests

a. Heating Tests - by G. D. Arndt

Introduction

The SPS system sizing of a 1Km transmit array with 5GW of DC power out of the rectenna is constrained by a maximum power density limitation in the ionosphere (Ref. 1). A power density of $23 mw/cm^2$ has been postulated as the threshold level for nonlinear interactions between the microwave power beam operating at 2450 MHz and the heated ionosphere (Ref. 2). This threshold level places a maximum size on the antenna for a given power output at the rectenna, i.e., the 1Km, 5GW system. However, there is not sufficient experimental or theoretical data available to accurately predict the exact threshold level. Since the maximum power density, or threshold level, is a critical parameter in sizing the SPS system, a program is now underway to study the microwave beam/ionospheric interactions.

Microwave Beam/Ionoshpere Interactions

As the high power microwave beam passes through the ionosphere, a very small fraction of its energy is absorbed by the ions and electrons in the surrounding plasma. Although there are equal numbers of positive and negative charged particles, the electrons, because of their small mass, are dominant in interacting with the microwave beam. Energy is extracted from the microwave signal and adds to thermal energy of the electrons.

The simplist type of energy transfer is ohmic heating which, for the 2450 MHz microwave signal, is written

$$Q = 1/2\ \sigma\ E^2 = 1/2\ \frac{Ne^2\ \nu}{mw^2}\ E = k\ \ P_D\ \ \lambda^2 \qquad (1)$$

where E - is the peak value of the microwave electric field

σ - conductivity of the plasma

P_D - power density of microwave beam

λ - wavelength of microwave beam

k - a constant containing electron density, mass, and charge

ν - collision frequency (dependent upon altitude)

For the typical SPS system, the associated heating level in the ionosphere will be

$$P_D\lambda^2 = 30\ mw/cm^2 \bullet (12.25)^2\ cm^2 = 4.5\ watts \qquad (2)$$

As the ionosphere is heated, the electron density decreases in the F-region (150 - 300 Km) due to expansion of the plasma along the earth's magnetic field lines. Reductions in electron density of up to 40% of the ambient density have been calculated for the SPS beam passing through the F-region (Ref. 3). This reduction is similar to that produced by a strong

magnetic storm. The heated electrons spiral outward up and down along the field lines and thus diffuse, conducting heat away. The increases in electron temperature produced by the SPS system have been calculated for a mid-day ionosphere over Arecibo, P.R. to be (Ref. 4):

Height in Km	75	100	150	200	250	300
Ambient Electron Temp. (^{o}K)	200	300	1000	1700	1900	2000
Heated Electron Temp. (^{o}K)	2200	1600	1500	2500	2600	2600

The strong heating effects in the D-region (70-100Km) will produce an increase in electron density due to a reduced electron/ion recombination rate. The electron temperature will have a very large increase as shown in the previous chart. However, even though the electron temperature increases by an order of magnitude in the D-region the electron density is very small compared to the F-region density. These effects will be accompanied by changes in the chemical reaction rates for this region.

In the F-region the changes in electron temperature and electron density will at some level become large enough to produce nonlinear instabilities such as thermal self-focusing. This thermal self-focusing can produce large-scale irregularities of the ionosphere, with the striations aligned with the magnetic field lines. That is, the regions of high electron density tend to focus the microwave beam into regions of lesser density. The power density then increases in the focal region, giving more energy to the electrons, furthering reducing their density and continuing the self-focusing process. These regions of high and low density are aligned with the magnetic field lines and flow outward. The following diagrams show the field aligned, thermal self-focusing phenomenon (Ref. 5).

Since these high energy electrons produced by the thermal self-focusing move along the field lines, these disturbances or perturbations in the ionosphere may no longer be limited to the region around the high-power beam. The perturbations could possibly cover large geographic areas along the field lines. The main problems associated with nonlinear heating and density depletion are possible disruptions to existing communications and navigation systems due to fading, scattering, multipath, etc.

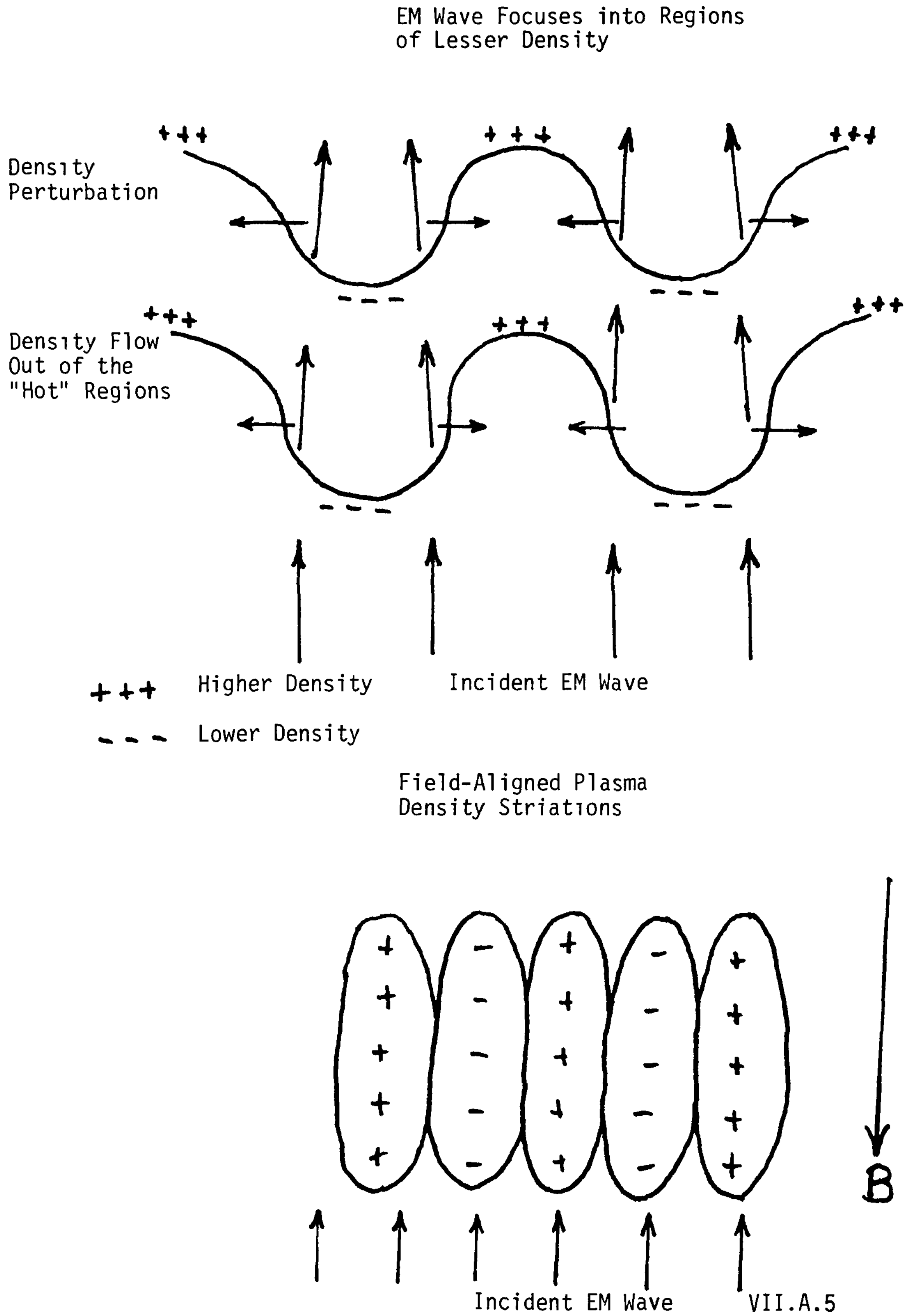
Study Program

A program to study the ionosphere/microwave beam interactions is now underway. Overall objectives of these programs include:

1. Determine power density levels (mw/cm^2) at which nonlinear interactions begin to occur.

2. Assess the effects of both ohnic and nonlinear heating on commerical communications and navigation systems.

Figure VII.A-2 -Thermal Self-Focusing at High Density Levels



3. Determine RFI effects on radio astronomy (scattering of microwave power beam and associated noise components by ionosphere).

As the first step to achieve these goals, a contract was awarded in 1976 with the following specific objectives:

O Determine analytically the threshold density levels for nonlinear interactions.

O Develop a detailed test program for full-scale tests to measure these interactions--includes parameter measurements, frequencines, facilities, and modification costs.

O Using the existing Arecibo antenna facility, making S-band measurements at a density of 1-2 mw/cm^2.

O Investigate possibility of laboratory plasma experiments.

This work is headed by Prof. W. E. Gordon of Rice University, who has been the team leader for low-frequency heating experiments at the Arecibo Observatory; Prof. F. W. Perkins of Princeton University and the National Center for Atmospheric Research (NCAR) is performing theoretical analyses. The study tasks are proceeding on schedule. The theoretical work by Perkins and Roble at NCAR is producing contours of electron temperature (illustrating the distortion along the field lines) and electron density for several ionospheric conditions. The frequency scaling laws that should apply for ohmic heating of the ionosphere (which is straightforward), for thermal self-focusing, and for communication scattering cross-sections are also being completed. A working paper has been written on scaled laboratory testing.

Arecibo Tests

The heating tests using the existing Arecibo antenna facility are scheduled for June 2-15, 1977. The following equipment will be used in the tests:

Transmitters	Antenna
4-11 MHz, 200 KW	305m
430 MHz, 2MW	
2300 MHz, .5MW	

This equipment will produce an S-band power-density of 1-2 mw/cm^2 in the F-region. While this density is considerably lower than the 20-30 mw/cm^2 expected for an SPS station, it will be a first step in reaching that level and provide valuable experimental data not now available.

Other agencies cooperating in the tests are the Aeronomy Laboratory of NOAA at Boulder and the Institute du Globe at Paris. A 50 MHz diagnostic radar will be set up on Guadeloupe in the Leeward Islands by the Institute du Globe and operated by the NOAA staff. This station is located where the radar beam is perpendicular (for maximum reflection) to the magnetic field lines at 220 Km altitude over Arecibo. It is capable of observing field-aligned irregularities produced by thermal self-focusing from Arecibo. The thermal self-focusing will be attempted by all three transmitters as listed previously.

The limited tests using the existing facilities at Arecibo were completed June 15, 1977. The results may be summarized as follows:

Three heating frequencies were used - 4-11 mega hertz, 430 MHz, and 2300 MHz. The power density for the 430 MHz test at a height of 200 kilometers was .6 mW/cm^2, "which is 1/12 of the equivalent SPS level" in a 1 kilometer heated cross-sectional area; the corresponding density for the 2300 MHz S-band test was 1.1 mW/cm^2, "which is 1/20 of the equivalent SPS level" in a 200 meter heated cross-sectional area. No non-linear heating effects were observed by the diagnostic radar at Guadeloupe for any of the heating frequencies. These negative results were as anticipated.

These tests and analytical analysis will greatly enhance knowledge about the SPS microwave beam/ionosphere interactions. However, to fully resolve the ionosphere issues, the ionosphere must be heated from the ground to an equivalent SPS level. Preliminary costs estimates for modifying the Arecibo Observatory for full-scale testing is about $3M. The detailed costs for modifying Arecibo and the Platteville, Colorado facility will be included in the contractor report, scheduled for August 1977.

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VII. ENVIRONMENTAL FACTORS

A. Microwave Transmission Reception

2. Ionosphere Tests

b. Communications

Once the effects of the MW beam on the isophere is determined, the immediate question is: "What effect will these ionospheric disturbances have on users of the ionosphere?" Users are defined as those who are dependent on communication, navigation, and radar systems which utilize the ionosphere as a transmission medium. Two areas of possible effects require investigation in order to answer the basic question.

Ohmic heating effects on communications services will require investigation. These will occur primarily near the MW beam penetration of the ionosphere. Determination should be made of the extent and occurrence of disturbances, effect of electron density depletion caused by ohmic heating, and effect of scintillation and scatter.

Another area requiring investigation is the nonlinear effects of the ionosphere on communication services. Primary here is the question of the geographical extent of nonlinear interactions. Determination should be made of extent and occurrence of the disturbances, as well as the geographical area affected. Communication affects caused by variations in election densities, scintillation and scatter also require definition.

Definition of the above areas can be accomplished using both analytical and testing techniques. If testing continues to look desirable, the test program should be conducted in conjunction with the ionosphere heating tests discussed in section a. above.

Communication Effects - ionosphonic disturbances and their effects on communication services are generally well known and documented in the literature.

The more extensive disturbances which are known at this time and which are generally predictable are associated with solar flares and can be classified as ionospheric disturbances, storms, and polar region absorption. The disturbance takes the form of abnormally high absorption in the D layer, phase and amplitude changes, changes in the effective height of reflection and sudden frequency deviations. Ionospheric storms are accompanied by magnetic disturbances and are usually more intense in the auroral regions. These changes in the ionosphere can cause reduction of the critical frequency in the F_2 region, and radio blackout due to absorption, enhancement of spread F and sporadic E.

The less extensive disturbances are associated with electron configurations that move with time and are localized. They are not extensive because of their local nature. Anticipation of the ionospheric disturbances caused by one SPS MW beam may be localized, but has the possibility of spreading geographically along the magnetic lines if nonlinear effects are created.

For a complete complement of over 100 SPS's, the "localized" effect will also spread geographically. It is for these reasons that a thorough understanding of ionospheric effects on communications services should be developed.

Communications, Radar and Navigation Systems (COMMRAN) - The possible COMMRAN systems which may be affected by MW beam disturbances of the ionosphere are numerous. It will be extremely difficult to assess the affects on all the COMMRAN systems. Any program of this magnitude will require grouping into types for analytical investigations and possibly a further combining into groups for a possible test program. Basic types of systems include, but are not limited to:

a. Long-haul communications - typical HF frequencies of 3-30 MHz which depend on ionospheric reflection for long range communications. Users include military, civilian and amateur.

b. Commercial satellite communications - typical UHF to S-band frequencies of 1.2 - 4.0 GHz.

c. Military satellite communications - typical VHF/UHF frequencies of 225 - 400 MHz for space-to-ground and space-to-aircraft communications.

d. Military radars for large area surveillance - typical HF frequencies of 5 - 30 MHz which utilize the ionospheric reflection.

e. Military radars for space tracking - typical frequencies are in the VHF-UHF bands.

f. Satellite global positioning system - typical frequencies in UHF band are 1.2 and 1.6 GHz.

g. Omega/Loran C navigation aids - typical frequencies in VLF band of 10 KHz require use of ionospheric reflection.

Solar Power Satellite (SPS) Systems - Two systems on the SPS may be affected by ionospheric disturbances caused by the MW beam. These are the phase control system's pilot beam transmitted from the ground and the SPS antenna pointing control signal. As mentioned in the "Technology Advancement Report," JSC-12702, these two systems should be investigated further. Because of the criticality of antenna pointing and MW beam phasing, it is deemed necessary to test the effect of ionospheric heating on these systems. These tests would have to await either a LEO or GEO SPS test article. When these test articles are available, ionospheric heating should be done, simultaneous with the phase control and antenna pointing tests. Transmission of these control signals could then be directed through the heated portion of the ionosphere.

Approach for Investigating COMMRAN System Effects - Because of the overwhelming number of communication service users who are affected by the ionosphere, a logical methodology of categorizing users and systems must be established. The approach outlined below intentionally omits SPS design

and development activities and concentrates only on investigating ionospheric heating effects on the COMMRAN systems. The approach should include:

a. Survey of all COMMRAN systems which depend on or are influenced by the ionosphere.

b. Categorize systems into similar/related types.

c. Based on predicted changes in the ionosphere due to the MW beam, perform in-house and/or contract study to determine frequency bands affected, time, duration and extent of changes, etc. on the typical COMMRAN systems.

d. If study warrants further investigations, establish the overall testing plan.

e. Perform comprehensive selection of COMMRAN systems to be tested.

f. Assimilate baseline test data on selected COMMRAN systems.

g. Determine optimum location of transmitters and receivers for the selected systems.

h. Coordinate availability of selected systems with using agencies or suppliers.

i. Coordinate availability of ionospheric heating facility.

j. Coordinate availability of transmitter/receiver locations with proper authorities.

k. Develop testing procedures in coordination with COMMRAN system users and ionospheric heating test facility personnel.

l. Determine methods of real-time coordination during testing activiites.

m. Determine test times and resources required to conduct test program.

n. Assimilate necessary COMMRAN systems, attendant support equipment, and personnel.

o. Coordinate test procedures with all affected parties.

p. Conduct baseline tests on selected COMMRAN systems without ionospheric heating, including appropriate day/night cycle conditions.

q. Conduct tests with inosphere heated to expected SPS operational levels.

Summary - The above discussion has focused on the need for determining how ohmic heating, non-linear thermal self-focusing and other ionospheric disturbances will affect communication users of the ionosphere. Although it is generally understood how the MW beam will affect the ionosphere, and individual users of communication services understand how ionospheric disturbances affect the service, it is recognized that an extensive investigation should begin to assure that the SPS MW system will not adversely affect worldwide communications dependent of the ionosphere. To this end, the above sections serve as an outline of issues to be investigated and approaches to be considered.

VII. A. 3 MICROWAVE RADIATION BIOLOGICAL EFFECTS

By D. S. Nachtwey, SD4

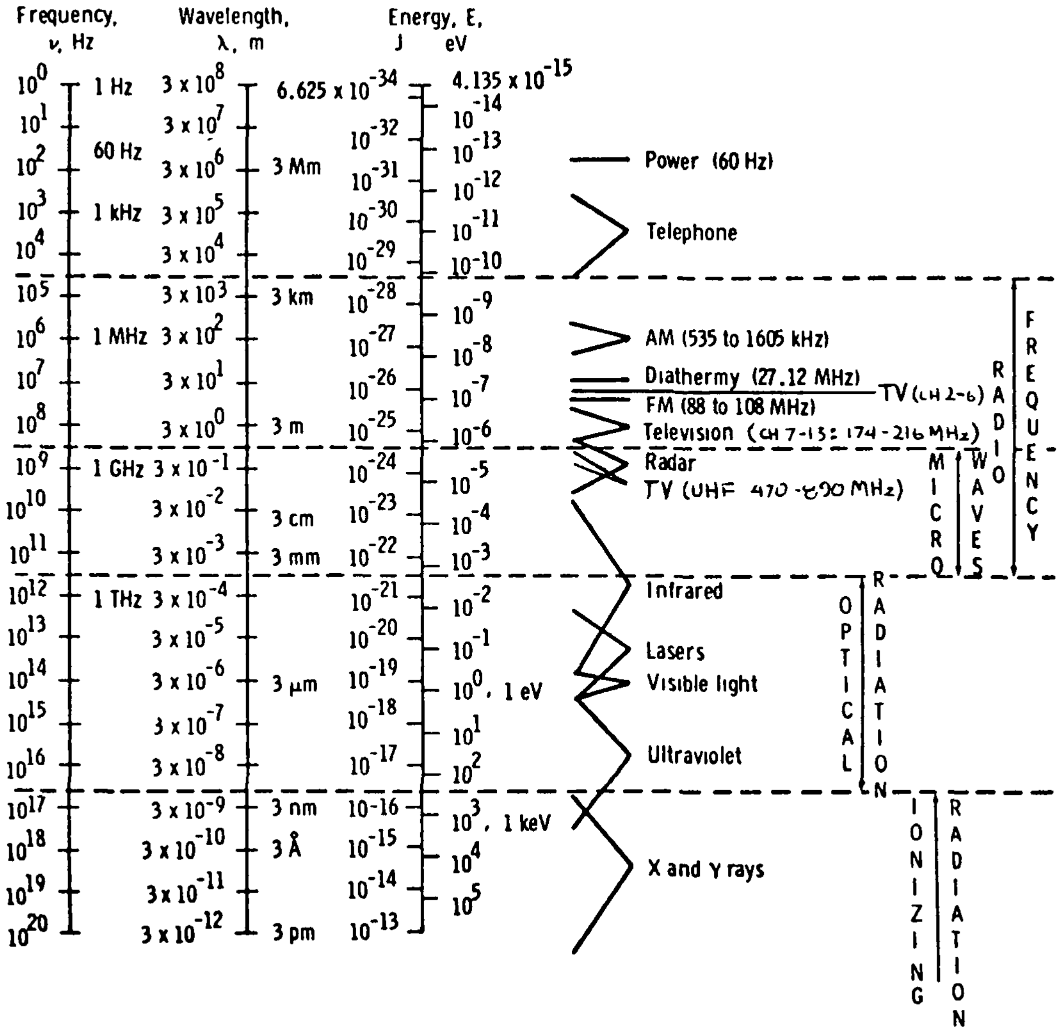
The Solar Power Satellite (SPS) microwave beam is potentially hazardous both in space and on the ground. Potential exposure situations to space workers could occur during power beam tests or SPS maintenance. In addition exposures to radars and communications transmitters are possible. Potential exposures of humans and other biota on the ground could occur at or near rectenna sites. In addition, very low level exposures of the public will occur over very large geographic areas from power beam side lobes (see Figure VII-A-1).

This section discusses some of the biophysical characteristics of radio-frequency (RF) radiation in general, some of the potential biological effects (primarily human effects), RF Radiation Exposure Standards, the philosophies underlying the standards, and areas requiring additional research.

Biophysical aspects of RF radiation. Because the assessment of the biological impact of RF radiation is highly dependent upon the basic biophysical aspects of the interaction of the radiation with biological systems, a somewhat extensive discussion of these biophysical aspects may be fruitful. RF radiation like all electromagnetic (EM) radiation consists of a stream of photons each possessing a discrete energy. The behavior of EM photons can be described by wave equations so the different types of EM radiation are designated either by their energy, their wavelengths, or the frequency of the waves in cycles per second (Hertz or Hz). The energy of the photon, is directly related to its frequency and inversely related to its wavelength (see Figure VII-A-3).

A biological effect of any EM radiation requires that the photon interact with molecules within the organism and the energy of the photon be absorbed; without absorption of energy, there is no possibility for a biological effect. For high energy photons such as those in x- or gamma-rays, the photon's absorbed energy can cause ejection of an orbital electron, i.e. it can cause ionization and thus detrimental alteration of the molecule and possibly the organism. For lower energy photons such as ultraviolet radiation, the photon does not cause ionization but can raise an orbital electron in a molecule to an excited state which can then cause a detrimental chemical change in the molecule. As the frequency of the EM radiation decreases further the absorbed photons are not sufficiently energetic to excite orbital electrons, but they can affect the molecule by increasing its vibrational, rotational, or translational energy, i.e. increase its temperature. In general, RF photons

*The major source of information for this section is a review by S. M. Michaelson (20), parts of which have been extracted verbatim.



Radiofrequency bands

Frequency (MHz)	Designation	Definition
0 03	VLF	Very low frequency
0 03 0.3	LF	Low frequency
0 3-3	MF	Medium frequency
3-30	HF	High frequency
30-300	VHF	Very high frequency
300-3000	UHF	Ultrahigh frequency
3000-30 000	SHF	Superhigh frequency
30 000-300 000	EHF	Extremely high frequency

VII-A-3. Electromagnetic radiation spectrum (from refs. 19 & 20).

cannot ionize or excite orbital electrons no matter how many are absorbed: The necessary minimum energy for ionization of biological molecules is about 10 eV; for excitation, it is about 1 eV. In contrast, the energy values of RF photons all lie in the range 10^{-3} to 10^{-10} eV. Therefore, in biologic systems, absorbed RF energy does not cause direct chemical change, but is rapidly equilibrated among the degrees of freedom of the system with the net effect being only an increase in general or localized temperature of the tissue. Such heating results from both ionic conduction and vibration of the dipole molecules of water and proteins (10). If sufficiently great, heating can of course cause damage to molecules (e.g. denaturation of proteins), cells (e.g. membrane breakdown), and organs.

Radiofrequency radiation transmission, scattering, and absorption are usually considered at the macroscopic wave level rather than as photonic interactions. Thus, these EM waves are characterized by an electric field vector, E (V/m), a magnetic field vector, H (A/m), and a propagation vector k (m^{-1}). Far from the wave source, the electric and magnetic field vectors are perpendicular to each other and both are perpendicular to the direction of propagation along k. This far-field EM radiation is planewave radiation. Close to electromagnetic sources and around electromagnetic scattering objects, different configurations and relative magnitudes of the E, H, and k vectors are possible.

The total amount and the distribution of the absorbed electromagnetic power in biological tissue exposed to electromagnetic fields is a function of many factors, including reflective loss, the magnitude of the electric field (E), magnitude of the magnetic field (H) that penetrates, the relative stored energy in the magnetic and electric fields, the polarization of the fields, the source and tissue configurations, the tissue composition, frequency, environmental factors, and others. In general, however, the penetration and absorption of RF energy is dependent upon the electrical properties of the absorbing medium, specifically, its dielectric constant and electrical conductivity, both of which properties change as the frequency of the applied RF field changes. Values of dielectric constant and electrical conductivity and depth of penetration have been determined for many tissues (see Table VII-A-1). The absorption of RF energy is high and therefore the depth of penetration is low in tissues of high water content such as muscle, brain tissue, internal organs, and skin, while the absorption is lower in tissues of low water content such as fat and bone. Reflections between interfaces separating tissues of high and low water content can produce standing waves accompanied by hot spots that can be maximum in either tissue, regardless of dielectric constant or conductivity. The degree of these reflections are also frequency-dependent (Table VII-A-1).

In considering the biologic effects of RF energy, the wavelength or frequency of the energy and its relationship to the physical dimensions of objects exposed to radiation become very important factors

TABLE VII-A-1 - PROPERTIES OF RF RADIATION IN BIOLOGICAL MEDIA[a]

(a) Media with high water content

RF radiation		Muscle, skin, and tissues							
Frequency, MHz	Wavelength in air, cm	Dielectric constant, ϵ_H	Conductivity, σ_H, mo/m	Wavelength, λ_H, cm in medium	Depth of penetration,[b] cm	Reflection coefficient, air/muscle interface		Reflection coefficient, muscle/fat interface	
						r	ϕ	r	ϕ
1	30 000	2000	0 400	436	91 3	0 982	+179	—	—
10	3 000	.60	625	1.8	21 6	956	+178	—	—
27 12	1 106	1.3	.612	68 1	14 3	925	+177	0 651	-11 13
40 68	738	97 3	693	51 3	11 2	913	+176	652	-10 21
100	300	71 7	889	27	6 66	881	+175	650	-7 96
200	150	56 5	1 28	16.6	4 79	844	+175	6.2	-8 06
300	100	54	1 37	11 9	3 89	825	+175	592	-8 14
433	69.3	53	1 43	8 76	3 57	803	+175	562	-7 06
750	40	52	1.54	5 34	3 18	779	+176	532	-5 69
915	32 8	51	1.60	4 46	3 04	772	+177	519	-4 32
1 500	20	49	1 77	2 81	2 42	761	+177	.506	-3 66
2 450	12 2	47	2 21	1 76	1 70	754	+177	.500	-3 88
3 000	10	46	2.26	1 45	1 61	751	+178	495	-3 20
5 000	6	44	3 92	.89	788	749	+177	502	-4 95
5 800	5 17	43 3	4 73	.775	720	746	+177	502	-4 29
8 000	3 75	40	7 65	578	413	744	+176	513	-6 65
10 000	3	39 9	10.3	464	343	743	+176	518	-5 95

(b) Media with low water content

RF radiation		Fat, bone, and tissues							
Frequency, MHz	Wavelength in air, cm	Dielectric constant, ϵ_L	Conductivity, σ_L, mmho/m	Wavelength, λ_L, cm in medium	Depth of penetration,[b] cm	Reflection coefficient, air/fat interface		Reflection coefficient, fat/muscle interface	
						r	ϕ	r	ϕ
1	30 000	—	—	—	—	—	—	—	—
10	3 000	—	—	—	—	—	—	—	—
27 12	1 106	20	10 9 to 43 2	241	159	0 660	+174	0 651	+169
40 68	738	14 6	12 6 to 52 8	187	118	617	+173	652	+170
100	300	7 45	19 1 to 75 9	106	60 4	.511	+168	650	+172
200	150	5 95	25 8 to 94 2	59 7	39 2	458	+168	612	+172
300	100	5 7	31 6 to 107	41	32 1	438	+169	592	+172
433	69.3	5 6	37 9 to 118	28 8	26 2	.427	+170	562	+173
750	40	5 6	49 8 to 138	16 8	23	.415	+173	532	+174
915	32 8	5 6	55 6 to 147	13 7	17 7	417	+173	519	+176
1 500	20	5 6	70 8 to 171	8 41	13 9	412	+174	506	+176
2 450	12 2	5 5	96 4 to 213	5 21	11 2	406	+176	500	+176
3 000	10	5 5	110 to 234	4 25	9 74	406	+175	495	+177
5 000	6	5 5	162 to 309	2 63	6 67	.393	+176	502	+175
5 800	5.17	5 05	186 to 338	2 29	5 24	.388	+176	502	+176
8 000	3 75	4 7	255 to 431	1 73	4 61	371	+176	513	+173
10 000	3	4 5	324 to 549	1 41	3 39	363	+175	518	+174

[a]From Johnson and Guy (ref. 10)

[b]Depth at which power density reduced to e^{-2} (13.5%)

with major implications for the extrapolation of results of animal studies to effects on man. The absorption of energy radiating from a source into space depends upon the relative absorption cross section of the irradiated objects. Thus, the size of the object with relation to the wavelength of the incident field of photons plays a role. At very low frequencies (long wavelength), a biological specimen absorbs very little electromagnetic energy. Absorbed energy increases rapidly with frequency up to a resonance region where the animal body dimensions are approximately 0.4 of the wavelength in free-space. At frequencies greater than the resonance frequency, total absorbed energy slowly decreases. The orientation of the animal body with its variable dimensions (height, width, thickness) to the planes of the various fields also plays a role. Johnson et al (11) have calculated the absorbed energies for prolate spheroids approximating the dimensions of man and laboratory animals used in microwave research. Figure VII-A-4 shows the absorbed energies as a function of frequency and long-axis orientation of a man-sized prolate spheroid to the various field vectors. (Other studies are in progress using a more realistic simulated configuration, e.g. an ellipsoid.) It may be seen in Figure VII-A-4 that orientation to the E-field vector is an order of magnitude more effective than orientation to the other vectors at frequencies below the resonance point at $\sim$ 70 MHz. Beyond this and up to and beyond about 2 GHz the orientation to the E-field and H-field vectors are about equally effective.

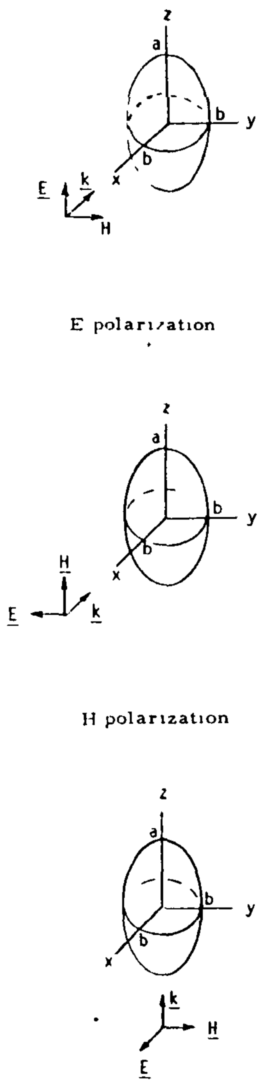
In Figure VII-A-5, similar calculations for a small rat are presented. A comparison between the graphs for man and those for the rat shows that for a given power density at a given frequency the amount of absorbed energy in man can be orders of magnitude greater than that for the rat whereas, at higher frequencies, absorption can be orders of magnitude greater for the rat than for man. Thus if some biological effect can be produced in a rat at say a power density of 100 mW/cm^2 , the power density required to produce the same amount of absorbed energy in man may be substantially different.

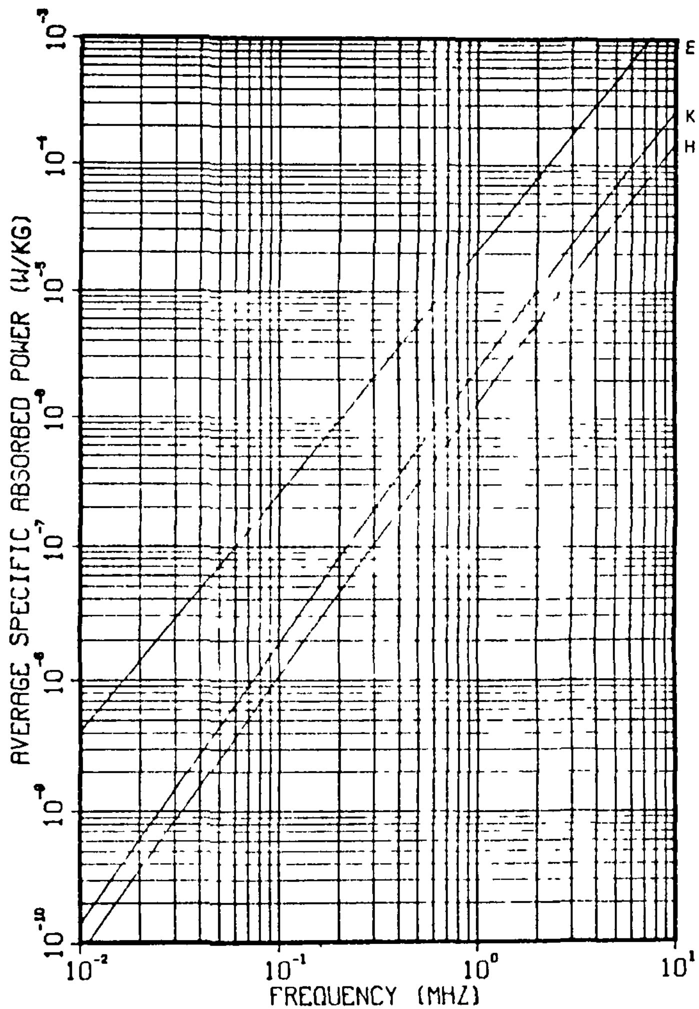
Although these calculations using a simple model provide only approximations of energy absorption, they serve to illustrate the following points:

a) The power density by itself is a poor indicator of absorbed energy.

b) Because frequency is such an important factor in determining the absorbed energy from a given power density, assessment of risks and setting of exposure standards should be further broken down into smaller frequency bands.

c) For humans, the frequencies near and beyond 70 MHz are the most important to consider because they are absorbed more readily.





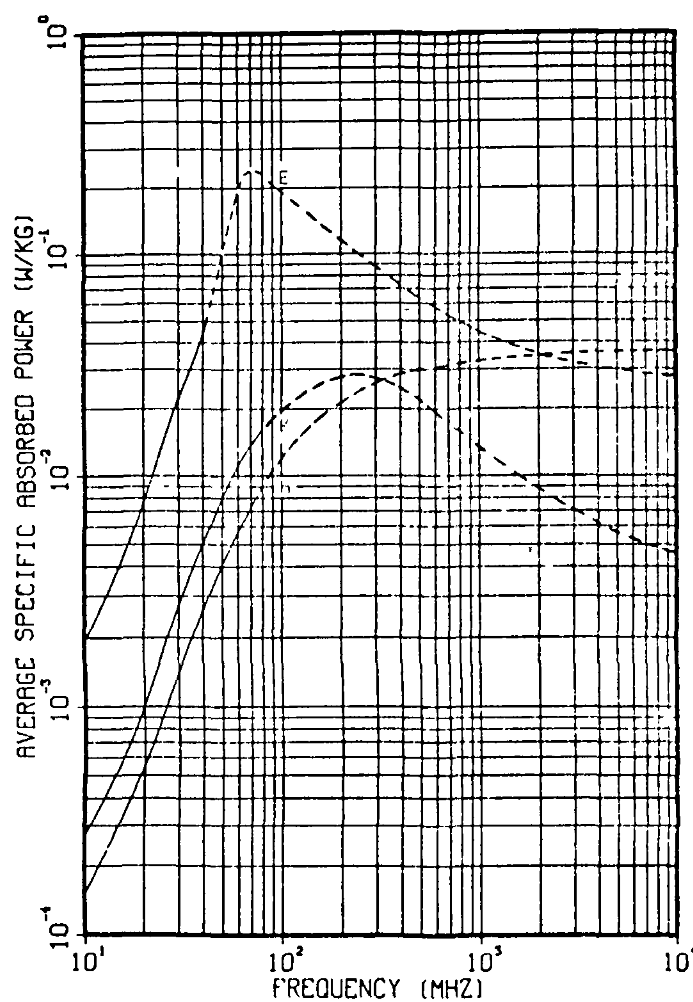


FIGURE VII-A-4 Average specific absorbed power in a prolate spheroidal model of an average man, for the three standard polarizations. a = 0.875 m, V = 0.07 m^3. Incident power density is 1 mW/cm^2

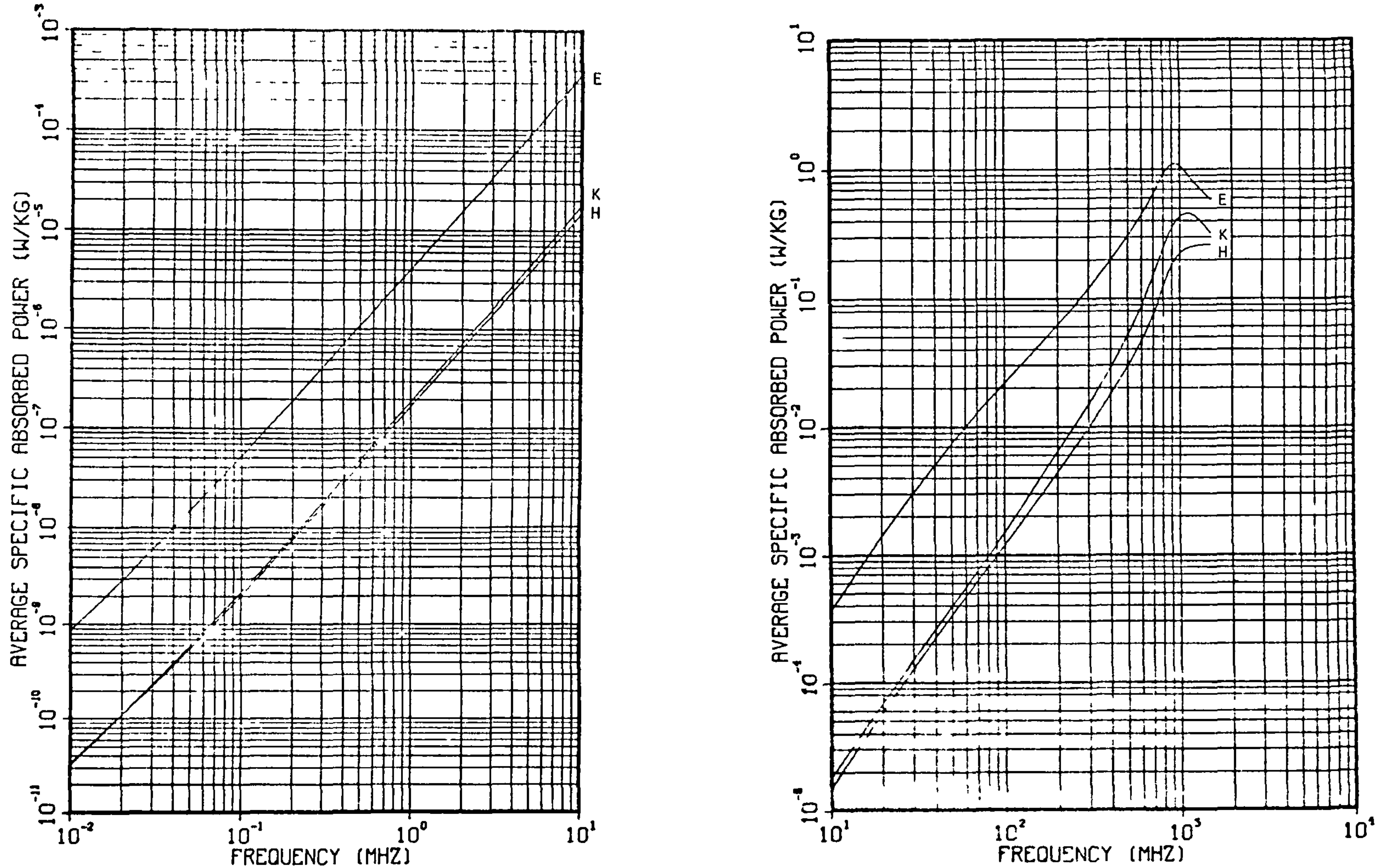


FIGURE VII-A-5 Average specific absorbed power in a prolate spheroidal model of a small rat, for the three standard polarizations a = 0 07 m, V = 1 1 x 10^{-4} m^3 Incident power density is 1 mW/cm^2

d) Extrapolation of results from animal studies, performed at some specific frequency and power density, to an expectation for effects on man exposed at the same frequency and power density may be grossly misleading.

e) In setting exposure standards, the random orientation of persons to the various vectors of the beam should be considered; the most critical orientation should set the limiting factor. For a more detailed discussion of the interaction of RF radiation with biological materials, Reference (9), by A. W. Guy and (11), by Johnson et al, may be consulted.

<u>Thermal effects on organisms</u>. Body temperature increase during exposure to RF radiation depends on 1) the specific area of the body exposed and the efficiency of heat elimination; 2) intensity of field strength; 3) duration of exposure; 4) specific frequency or wavelength; and 5) thickness of skin and subcutaneous tissue. These variables determine the percentage of radiant energy absorbed by various tissues of the body (29, 30).

In partial body exposure under normal conditions, the body acts as a cooling reservoir, which stabilizes the temperature of the exposed part. The stabilization is due to an equilibrium established between the energy absorbed by the exposed part of the body and the amount of heat carried away from it. This heat transport is due to increased blood flow to other parts of the body, which are maintained at normal temperature by heat-regulating mechanisms of the body such as heat loss due to sweat-evaporation, radiation, and convection. If the amount of absorbed energy exceeds the optimal amount of heat energy which can be handled by the mechanisms of temperature regulation, the excess energy will cause continuous temperature rise with time. Fever, and under some circumstances, local tissue destruction can result (29, 30). Not all parts of the body are equally susceptible to temperature rise: different parts vary in the ability to sense thermal stimulation and respond by increasing blood flow. The degree of innervation and vascularization together determine the body's response. Thus, the most susceptible parts of the body are those that are not as well protected by these physiological phenomena. Such areas include the eye lens, testes, gall bladder, and parts of the gastrointestinal tract. It has been shown that damage to these tissues can occur without significant rise in oral or rectal temperature (14).

Total body irradiation of organisms the size of humans may be considered in large measure to be partial body irradiation. As seen in Table VII-A-1, the depth of penetration may be only a few centimeters for many RF radiation frequencies. Conveniently, as the frequency of the radiation and its associated photon energy increases, the depth of penetration decreases allowing the highly vascularized surface tissues to effectively dispose of the heat (33).

Non-thermal effects in organisms. There have been many reports of so-called non-thermal effects of RF radiation, especially by investigators in the Eastern European countries. The validity of the existence of true non-thermal effects of low levels of RF radiation has been challenged by American and Western European investigators. In part, the controversy reflects a difference of definition of non-thermal effects: The Eastern Europeans consider any biological effect of RF radiation which is not accompanied by a generalized heating of the organism to be a "non-thermal" effect. The definition used by Western country investigators allows for localized, hot-spot-type heating, even though unmeasurable because of technical difficulties.

Given the very low energy of the photons of RF radiation, it is most likely that almost all observed biological effects can be attributed to thermal effects. It does not appear to be fruitful to dwell further on any distinction between thermal and non-thermal effects.

PHYSIOLOGICAL EFFECTS OF RADIO-FREQUENCY RADIATION

Systematic research on the biological effects of RF radiation was begun immediately after World War II (31). The results of these investigations are available in reports of the "Tri-Service Program" (17), reviews (5, 12, 16, 20, 21, 27), books (8, 15, 22, 23, 32), and symposia proceedings (4, 6, 19). Glaser (7) has recently prepared a comprehensive bibliography of the literature on RF and microwave bioeffects. Some reported effects are listed in Table VII-A-2 (compiled from Reference 20).

Extensive investigations into microwave bioeffects during the last quarter century show conclusively that, for frequencies between 1200 and 24,500 MHz, exposure to a power density of 100 mW/cm^2 for 1 h or more, can produce pathophysiologic effects of a thermal nature. Such effects are characterized by temperature rise, which is a function of the thermal regulatory processes and active adaptation of the animal. The end result is either reversible or irreversible change, depending on the conditions of the irradiation and the physiologic state of the animal. At power densities below 100 mW/cm^2, however, evidence of pathological changes is nonexistent or equivocal (20).

The literature on the biologic effects of radio- and low-frequency ($\leq$30 MHz) electromagnetic radiation has been reviewed by several authors (2, 13, 15, 18, 22, 24). Bollinger (3) has reported on an extensive biomedical study of low-frequency RF radiation. Short-term (1 h) exposures of monkeys to 10.5, 19.3, and 26.6 MHz, under experimental conditions which employed 100 to 200 mW/cm^2, did not produce discernible biologic effects.

Michaelson (20) has reviewed in greater detail the results briefly listed in Table VII-A-2. He has pointed out the limitations in some of the data which make it inapplicable for supporting the idea that exposures to low power densities cause pathological effects; for example, he

TABLE VII-A-2 - SOME BIOLOGICAL RESPONSES TO RF RADIATION[a]

Response	Remarks
Perception of heat	13 to 59 mW/cm^2 for 4 sec (3000 MHz and 10 000 MHz)
Pain threshold	1800 mW/cm^2 for 60 sec (3000 MHz)
Cataracts	Lens clouding when temperature of lens increases by 4 K (4° C) Accumulation of subclinical damage at low power densities for short durations may yield cataracts Evidence still equivocal.
Reproductive detriment	
Testes	Intrascrotal temperature rise of >1 K (>1° C) by RF radiation or any other means reduces viable sperm count, this effect is usually reversible Exposure to 2880 MHz at 5 mW/cm^2 for an indefinite period is the "threshold" for evidence of testicular damage in the most sensitive dog out of 35 dogs tested. Exposure to 3000 Mhz at 8 mW/cm^2 did not affect mating of mice or rats.
Ovaries	No evidence that exposures to 10 mW/cm^2 or even somewhat greater interfere with reproduction
Visceral Effects	
Gastric ulcers	>100 mW/cm^2 for ≥ 10 min
Delay of gastric secretion and emptying	0 05 to 1 mW/cm^2 for 30 min Reversible.
Hematopoietic effects	
Leukocytosis, lymphocytopenia, eosinopenia, red blood cell life span alteration, impaired bone marrow function, hemoglobin decreases, platelet decrease, reticulocytosis, etc	Generally, long exposures to >10 mW/cm^2 are required to yield an effect. Effects are generally reversible
Cardiovascular effects	
Blood flow changes, blood pressure decrease, heart rate increase, etc	Effects generally attributable to peripheral vasodilation and hemodilution in response to heat stress
Central nervous system	
Agitation, drowsiness, muscular weakness, electroencephalogram (EEG) changes, avoidance behavior, altered conditioned response, decreased endurance, headache, etc.	Large number of studies, some conflicting results Eastern Europeans claim effects at <10 mw/cm^2 investigators in Western countries have not always observed these effects even at higher exposure levels This is the area of greatest controversy

[a]Compiled from reference 20

points out the lack of appropriate controls in some cases, other mitigating circumstances (e.g. concurrent exposure to ionizing radiation) that might be responsible for an effect, and the reversibility of most of the phenomena observable at low exposure levels. He indicates that many of the biological responses observed with exposures at power densities less than 100 mW/cm^2 are not to be considered pathological but reflect physiological adaptations and stress reactions.

As regards effects on the human central nervous system produced by low levels of RF radiation, Michaelson (20) summarizes and discusses the reported effects as follows: "Effects in man referrable to CNS sensitivity have been described (5 references cited). Most of the reported effects are subjective, consisting of fatigability, headache, sleepiness, irritability, loss of appetite, and memory difficulties. Psychic changes that include unstable mood, hypochondriasis, and anxiety have been observed. Compared to those in control groups, persons working in microwave fields of various intensities complain often of a heavy feeling in their heads, headaches, fatigue, drowsiness in the daytime, irritability, poor memory, and a pain in the heart, usually of the aching, stabbing type. Objective symptoms are bright red, diffuse, persistent dermographia, hyperhidrosis, unstable arterial pressure, and angiopathy of the retina. Autonomic vascular instability is reflected in changes in the electrocardiogram (bradycardia, disturbance in intraventricular conduction). Mental disorders such as anxiety, insecurity, hypochondria, suicidal thoughts, and at a later state, delirium, terror, visual and auditory hallucinations, combined with impairment of sleep have been reported (one reference cited). Most of the subjective symptoms are reversible, and pathological damage to neural structures is insignificant. Most of the reports are based on subjective rather than objective findings. It should be noted that individuals suffering from a variety of chronic diseases may exhibit the same dysfunctions of the central nervous and cardiovascular systems as those reported to be a result of exposure to microwaves."

It is not clear whether the above reported subjective effects can be applied to a large fraction of the population or just to a small highly susceptible subpopulation or to a subpopulation concomitantly affected by other factors. These observations, nonetheless, indicate that RF radiation stress at low power densities may lead to performance decrements, perhaps similar to those occurring in hot environments.

PHYSIOLOGICAL LIMITS (STANDARDS)

Adequate protection of SPS workers from potential RF radiation hazards should be achieved by using the RF radiation exposure standards of the American National Standards Institute (ANSI) or the American Conference of Governmental and Industrial Hygienists (ACGIH) as criteria for design and/or operational procedures. These standards plus those of other agencies and countries are listed in Table VII-A-3.

TABLE VII-A-3- RECOMMENDED MAXIMUM PERMISSIBLE INTENSITIES FOR RADIOFREQUENCY RADIATION[a]

Maximum permissible intensity	Frequency, MHz	Country or source	Specifications
10 mW/cm^2	10 to 100 000	ANSI 1966, Canada 1966 National Institute of of Occupational Safety and Health (NIOSH)	1 mWh/cm^2 for each 6 min 8-hr workday
	30 to 30 000	Great Britain 1960	Daily exposure
	100 to 100 000	US Army and US Air Force 1965	10 mW/cm^2 continuous exposure
		France (military) 1969	10 to 100 mW/cm^2 limited occupational exposure (per hr) calculated as Minutes = $\frac{6000}{(X mW/cm^2)^2}$
		American Conference of Governmental Industrial Hygienists (ACGIH)	10 mW/cm^2 threshold limit value, 8 hr 10 to 25 mW/cm^2, 10 min/hr 25 mW/cm^2, ceiling value
		Sweden 1961	Occupational
		German Fed. Republic 1962 Netherlands	
1 mW/cm^2	All	Sweden 1961 France 1969	General public Prolonged occupational exposure
	>300	USSR 1965, Poland 1961	15 to 20 min/day (protective goggles required)
0.1 mW/cm^2	>300	USSR 1965, Poland 1961	2 to 3 hr/day
0.025 mW/cm^2	>300	Czechoslovakia 1968	Continuous wave 8 hr/day (occupational)
0.01 mW/cm^2	>300	USSR 1965 Poland 1961 Czechoslovakia 1968	Workday Workday (pulsed) 8 hr/day (occupational)
20 V/m E field 5 A/m H field	0.06 to 30	USSR 1965	
10 V/m	30 to 300	Czechoslovakia 1968	(pulsed) 8 hr/day (occupational)
3 V/m	30 to 300	USSR 1965	

[a]From references 19 and 20

The value of 10 mW/cm^2 listed as a maximum permissible intensity for continuous exposure reflects the simple physiological consideration that the amount of heat which the human body can transfer to the external environment is, under normal circumstances, about 10 mW/cm^2 of body surface which may be raised about tenfold under very favorable circumstances. This means that the human body's ability to absorb RF radiation energy without causing a continuous temperature rise is limited to a value somewhere between 100 and 1000 W. These values may be compared to the metabolic energy produced by a 70 kg man: about 100 W at rest and about 300 W after heavy labor. Calculations indicate that for most frequencies only a fraction of the 10 mW/cm^2 to which a human might be exposed would actually be absorbed (Figure VII-A-4). These considerations plus a review of the extensive body of experimental data then available from the Tri-Service-sponsored studies (17), led a committee of the American National Standards Institute (ANSI) to recommend in 1966, the 10 mW/cm^2 value as the standard (25). They reaffirmed the standard in 1973 (19). The basic standard reads as follows:

> "For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 to 100,000 MHz the radiation protection guide is 10 mW/cm^2 as averaged over any possible 0.1 hour period."

This standard does not set an upper intensity limit for very short-term ($<$ 0.1 h) exposures but sets a maximum energy density of 1 mWh/cm^2 averaged over the 0.1-h period (a time weighted average). The ANSI standard permits indefinite exposure to a maximum power density of 10 mW/cm^2. The guide applies whether the radiation is continuous or intermittent and is intended for the general public as well as workers.

These guides and exposure levels in force today appear to be entirely safe. So far, there is no documented evidence of injury to military or industrial personnel, or the general public, from the operation and maintenance of radars and other RF and microwave-emitting sources within the 10 mW/cm^2 limit of exposure (20).

Despite the apparent safety of the ANSI standards, microwave standards are undergoing frequent review and more detailed specification. The most recent statement on microwave standards is in the 1976 ACGIH (1) Notice of Intent to Change Threshold Limit Values (TLV). The full text of the intended change is as follows:

> These Threshold Limit Values refer to microwave energy in the frequency range of 300 MHz to 300 GHz and represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect.

Under conditions of moderate to severe heat stress the recommended values may need to be reduced.* Therefore, these values should be used as guides in the control of exposure to microwave energy and should not be regarded as a fine line between safe and dangerous levels.

Recommended Values:

The Threshold Limit Value for occupational exposure to microwave energy, where power density or field intensity is known and exposure time is controlled, is as follows:

1. For exposure to continuous wave (CW) sources, the power density level shall not exceed 10 milliwatts per square centimeter (mW/cm^2) for continuous exposure and the total exposure time shall be limited to an 8-hour workday. This power density is approximately equivalent to a free-space electric field strength of 200 volts-per-meter rms (V/m) and a free-space magnetic field strength of 0.5 ampere-per-meter rms (A/m).

2. Exposures to CW power density levels greater than 10 mW/cm^2 are permissible up to a maximum of 25 mW/cm^2 based upon an average energy density of 1 milliwatt-hour per square centimeter (mWh/cm^2) averaged over any 0.1 hour period. For example, at 25 mW/cm^2 the permissible exposure duration is approximately 2.4 minutes in any 0.1 hour period.

3. For repetitively pulsed microwave sources, the average field strength or power density is calculated by multiplying the peak-pulse value by the duty cycle. The duty cycle is equal to the pulse duration in seconds times the pulse repetition rate in Hertz. Exposure during an 8-hour workday shall not exceed the following values which are averaged over any 0.1 hour period:

Power Density	10 mW/cm^2
Energy Density	1 mWh/cm^2
Mean Squared Electric Field Strength	40,000 V^2/m^2
Mean Squared Magnetic Field Strength	0.25 A^2/m^2

4. Exposure is not permissible in CW or repetitively pulsed fields with an average power density in excess of 25 mW/cm^2 or approximate equivalent free-space field strengths of 300 V/m or 0.75 A/m.

*Mumford, W. S. "Heat Stress Due to R. F. Radiation," Proceedings of IEEE, Vol. 57, No. 2, Feb. 1969, pp. 171-178.

These standards appear to be the appropriate ones for the physiological limits to consider in SPS design and operations.

The ACGIH Standards (1) only apply to the frequencies, 300 MHz-300 GHz; but the ACGIH has filed a notice of "Intent to Study" RF radiation from 10 MHz to 100 MHz and microwave radiation from 100 MHz to 300 MHz. The possibility exists that future standards may be more specific as to frequency (33). For example, Rogers and King (26) suggest that under plane-wave (far-field) conditions the body could endure an RF radiation power density greater than 10 mW/cm^2 (E-field strength = 200 V/m) for frequencies in the HF band (3-30 MHz) and suggest that an electric field strength of 1000 V/m can be considered the safe limit for continuous daily exposure to RF radiation in the range below 30 MHz.

Mention should be made of the lower standards established by the Eastern European countries (see Table VII-A-3). These lower standards reflect the industrial hygiene philosophy of the USSR which, according to Magnuson et al (14), basically consists of the following:

(1) The maximum exposure is defined as that level at which daily work in that environment will not result in any deviation from the normal state, as well as not result in pathological effects.

(2) Standards are based entirely on presence or absence of biological effects without regard to the feasibility of reaching such levels in practice.

(3) The values are maximum exposures rather than time-weighted averages.

(4) Regardless of the value set, the optimum value and goal is zero. USSR maximum permissible exposure (MPE) values are not rigid ceilings but, in fact, excursions above these values within reasonable limits are permitted and the MPE's represent desirable values for which to strive rather than absolute values to be used in practice. Thus the standards used in the U.S. and in the USSR are not as irreconcilable as they might appear (20).

RESEARCH NEEDS

The main areas of uncertainty in the application of the ANSI or ACGIH Standards as design and/or operations criteria are as follows:

1) Dosimetric methods and models for studying the RF power densities or E and H field strengths at frequencies to be expected in various zones of the spacecraft or during EVA need to be developed to ascertain if the limits might be exceeded. Consideration should be given to the absorbed power from mixed fields produced by focusing and scattering effects within both the spacecraft and the bodies of spacecraft personnel.

2) The amount of heat which the human body can transfer to the environment in zero g, where natural convection does not play a role, needs to be determined. The 10 mW/cm^2 value appropriate for Earth conditions may not be applicable in zero g.

3) The extent to which low power densities (< 10 mW/cm^2) for extended periods will cause performance decrements by inducing headaches, fatigue, muscular weakness, irritability, etc., should be studied further.

4) The potential interactions of other environmental factors in space with the responses to RF radiation should be examined. For examples, RF heating effects on the biological responses to ionizing radiation need further study; additive thermal loading problems by RF radiation at 10 mW/cm^2 co-insulting with heat stress by partial failures of Environmental Control and Life Support Systems (ECLSS) or potential heat stress from heavy physical activity such as in EVA may cause a detrimental body temperature rise.

5) The direct impact on organisms and ecosystems in and near rectenna sites may not be significant, but the potential for a biospheric impact requires assessment. Organisms living under rectennas are likely to be sufficiently well shielded, but birds and insects flying slowly through the beam could be adversely affected with ramifying consequences to nearby ecosystems.

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VII ENVIRONMENTAL FACTORS

A. MICROWAVE TRANSMISSION - RECEPTION

VII-A-4 Rectenna Heating

R.K. Siler
Environmental Effects Office

Introduction

Since the summer of 1975, NASA Johnson Space Center has been studying the concept of placing solar power satellites (SPS) in geosynchronous orbit around the Earth. These orbiting satellites would collect and convert solar energy into a microwave beam which would be received on the ground by rectifying antenna arrays called "rectennas". Before it can be ascertained that such a space power system is a viable energy alternative for the future all direct and indirect costs must be carefully examined. The SPS concept appears to offer the advantage of having a minimum impact on the Earth's environment, i.e. there will be no particulate or chemical emissions nor hazardous waste products generated by energy production utilizing this concept. The importation of energy using this system might have meteorological side effects due to interaction of the transmitting microwave beam with the Earth's atmosphere or by releasing waste heat at the receiving rectenna.

The Environmental Effects Office at Johnson Space Center was requested to prepare a preliminary study of possible meteorological effects which the ground rectenna operation might create. The Environmental Effects Office technically coordinated with Lockheed Electronics Company, under support contract NAS 9-12200, to obtain the services of expert meteorologists, summarize the latest and most pertinent thinking in the area of weather modification, and prepare a preliminary study report. In addition to the three consultant groups selected to contribute to this effort, LEC solicited the opinion of several National Oceanographic and Atmospheric Administration (NOAA) experts working in fields related to the microwave transmission and heat island phenomena involved.

The consulting organizations placed under contract were:

1. Aeromet Inc.
   P.O. Box FF
   Norman, Oklahoma 73070
   Primary Consultant: D. Ray Booker, Ph.D.

2. Center for the Environment and Man, Inc.
   275 Windsor Street
   Hartford, Connecticut 06120
   Primary Consultant: G.D. Robinson, Ph.D.
   Contributing Consultants: M.A. Atwater, Ph.D.
   R.J. Ball

3. Simpson Weather Associates
   P.O. Drawer 5508
   Charlottesville, Virginia 22903
   Primary Consultant: Roger Pielke, Ph.D.
   Contributing Consultants: Michael Garstang, Ph.D.
   Joanne Simpson, Ph.D., CCM
   R.H. Simpson, Ph.D., CCM

Contributing consultants working in related area:

1. F.A. Gifford, Director
   Atmospheric Turbulence and Diffusion Laboratory
   NOAA
   P.O. Box E
   Oak Ridge, Tennessee 37830

2. M.T. Decker, Chief
   Environmental Radiometry
   Wave Propagation Laboratory
   NOAA
   Boulder, Colorado 80302

Discussion

Heat Sources

The Earth continously absorbs approximately 10^{17} watts of energy from the sun's radiation. An overall Earth average temperature is maintained by this energy but fairly large seasonal and diurnal temperature variations are observed. These natural variations represent the input and loss of large amounts of energy and are the driving forces behind the "weather".

Man's activities on the surface of the Earth which might have an impact on the weather be evaluated by comparing the energy released to that which normally flows in and out in the course of events. The environmental impact of the proposed rectennas can be evaluated by comparing the energy flux as a function of area and time with these existing sources and observing the consequent modification to the local weather pattern.

Cities have long been recognized as heat islands. Landsberg (1974)[2], reports values as high as 6°C in a small town (Corvallis, Oregon). The urban heat island effect is maximum about 3 hours after sunset on clear, calm evenings when the temperature difference between the paved streets and masonry walls of a city and the grassy countryside is at a maximum.

In most cases reported a far more typical heat island value is 1-3°C warmer over the city. Bornstein (1968)[3] found an average heat island of 1.6°C over New York City by using a low flying instrumented helicopter.

Dettwiller and Changnon (1976)[4] found the average heat island effect of Paris, France, Chicago and St. Louis at midday was 1-3°C warmer than the surrounding rural areas and extended 500-1500m above the city. The 100 year precipitation records indicated an increase of 19-38 percent in warm season rainfall. No change in winter precipitation was evident.

Harnack and Landsberg (1975)[5] studied several cases where convective precipitation was touched off by the Washington, D.C. metropolitan area. The energetics of the convective clouds were found to be consistent with the heat island effect available from the Washington area.

The urban effect of St. Louis has been studied in great detail by many research groups as a part of Project Metromex. Changnon, et. al. (1976)[6] summarized the Metromex studies and urban studies of seven other large cities and proposed a hypothesis for urban rainfall anomalies. The six largest cities, including St. Louis, had 10-30 percent summer precipitation increases in and downwind of the city. An increase in thunderstorm and hail frequency was also noted. For smaller cities, such as Tulsa and Indianapolis, there were no detectable changes. They concluded that the larger cities have about 25 percent more summer rainfall in and downwind of the city with more thunderstorms and hail. They suggest this effect is due to the differential heating and roughness between the city and country side, leading to more clouds and a greater chance for cloud mergers. A part of the effect is due to the addition of condensation nuclei, leading to more efficient condensation-coalescence processes. They found no significant winter effect on precipitation amounts.

Lindquist (1968)[7], Potter (1961)[8] and other have reported cases of urban-induced precipitation anomalies. It appears that the effect is most likely when significant winter precipitation is derived from instability showers, rather than large overrunning systems. Since most snow falls at temperatures near the freezing mark, an obvious effect of a heat island is to melt more snow, causing it to fall as rain or drizzle.

Heating effects have been modeled and several studies have been conducted on how urban areas may effect the weather. The literature describing these studies seems to indicate the following:

1. Large metropolitan areas produce a heat island effect of nominal value between 1°C and 3°C but could increase to 10°C under certain conditions.

2. These effects are responsible for up to 30 percent increases in warm season rainfall, more thunderstorms, and more hail.

3. Winter season precipitation amount changes were indicated but not firmly established. Any such effect is probably restricted to precipitation from instability showers.

4. Any effects are restricted to about 50 km downwind.

5. The most likely winter effect is to cause more snow to melt and fall as rain.

6. Part of the precipitation changes are due to microphysical changes not related to the heat island effect.

7. Smaller cities, such as Tulsa and Indianapolis, have not been found to have a significant effect on precipitation.

Malkus (1963)[9] reviewed several of her earlier studies of the heat island effect of small, flat tropical islands, which are frequently observed to produce afternoon convective clouds which often produce rain. While this effect is quite common and is easily observed, she pointed out that it is very dependent on wind speed and direction, atmospheric stability and other factors. She cast some doubt on the prospect of the same phenomenon occurring regularly over land. The effect is most likely to occur where convective cloud bases are low and stability is marginal. Mahrer and Pielke (1976)[10] obtain values of energy released per second due to turbulent surface heat flux of up to 400 watts/m^2 in their numerical simulation of the air flow over Barbados. This magnitude of heating causes a significant alteration of the low level wind and thermal profile, along with the development of convergence downwind from the Island.

Black and Tarmy (1963)[11] sought to prove that extensive areas coated with asphalt could be used to produce rain downwind and create arable land in certain desert coastlines. Their calculations indicated that balck strips of 15 to 80 km would be a cost effective means of producing an additional 50 mm of rainfall annually in some areas.

Additional estimates of energy release are available from other sources. Rosenberg (1974)[12] gives a daily average of 145 watts/m^2 for the undepleted solar radiation (undepleted by atmospheric attenuation) received on a horizontal surface at 40°N in January. Kaimal et.al. (1976)[13] obtained energy release rates on the order of 100 watts/m^2 over northwest Minnesota during a typical day.

Cities and urban areas are compared with other heat sources, estimated by Hanna and Swisher (1971)[14] and Hanna and Gifford (1975)[15], in Table VII-A-4. The SPS rectenna waste heat is fairly small compared to these other sources.

C-7

Table VII-A-4 Comparison of Natural and Man-Made Energy Sources

Source	Power Density	Typical Area/Scale	Time Interval	Total Power
Global Solar Energy Rec	1353 watts/M^2	Global($5.1 \times 10^8 KM^2$)	Continuous	1.73×10^{17} watts
Solar Energy Absorbed by Earth		Global(albedo ∿.33)	Diurnal Ave.	1.15×10^{17} watts
Solar Energy Absorbed by U.S.		Continental U.S.	Diurnal Ave.	1.8×10^{15} watts
Sensible Turbulent Heat Over Barbados	400 watts/M^2	600 KM^2	Daytime	2.4×10^{11} watts
Australian Bushfire	1000 watts/M^2	100 KM^2	Transient	10^{11} watts
Volcano[1]	100000 watts/M^2	1 KM^2	Continuous	10^{11} watts
Saturn V Booster	5×10^8 watts/M^2	300 M^2	150 Sec	1.5×10^9 watts
Super Energy Center or City	1000 watts/M^2	100 KM^2	Continuous	10^{11} watts
Large Power Park	1000 watts/M^2	100 KM^2	Continuous	10^{11} watts
Agro-Industrial Complex	100 watts/M^2	100 KM^2	Continuous	10^{10} watts
Suburban Area[2]	4 watts/M^2	100 KM^2	Continuous	4×10^8 watts
SPS Rectenna Waste Heat	7.5 watts/M^2	100 KM^2	Continuous[3]	1.68×10^{11} watts
Energy from SPS System		Urban/Industrial U.S.	Continuous[4]	1.12×10^{12} watts

[1] Surtsey in eruption
[2] Assumes 400 persons/KM^2 @ 10^4 watts dissipation per person
[3] Total rectennas = 224
[4] Assumes 224 rectennas each receiving 5 GW

Orbit Dynamics

At certain times of year the satellites will pass between the sun and earth, reducing temporarily the solar power reaching any point on the planet. To calculate the loss, it is necessary to look at some details of satellite construction and the nature of the orbit.

The satellite will be in geostationary orbit, radius 42.2×10^3 km. The earth's radius is taken as 6.4×10^3km. The solar collectors will rotate about a parallel to the earth's axis, but will not be rotated about an axis parallel to the plane of the ecliptic. Available solar power will thus vary as cos δ , δ being the sun's declination. If the mean solar power (the "solar constant") is I_o, the declination factor and the eccentricity of the earth's orbit result in the following variation in available power.

Northern winter solstice	$0.948\ I_o$
Northern spring equinox	$1.008\ I_o$
Northern summer solstice	$0.888\ I_o$
Northern autumn equinox	$0.994\ I_o$

There is a smaller diurnal variation caused by eccentricity of the satellite orbit. The situation at solstice is shown in Fig. VII-A-6a. There is no shading of the earth at this epoch.

The situation at equinox in the plane of the ecliptic is shown in Fig. VII-A-6b and that perpendicular to this plane is Fig. VII-A-6c. A belt of satellites over 60° of longitude, and those within about ±9° longitude of solar zenith lies between the earth and the sun at any one time. Solar power is reduced at a point on the equator for the period true solar noon (T.S.N.) ±2h. The reduction is constant at its maximum value over the period approximately ±1h 24 m from T.S.N.

The angular diameter of the sun is 9.3×10^{-3} radians and the satellite about 3.6×10^4 km from the earth's surface. The width of the penumbral band at the equator (Fig. 6c) is therefore, about 325 km, roughly 3° of latitude.

The situation at onset of occultation is shown in Fig. VII-A-7, which shows that there is some effect during the period when δ = ±8.9°, about 21 days on either side of each equinox. This is the eclipse period of Fig. IV-17 of JSC-11568, but note that that diagram does not include the effect on available power of eccentricity of the earth's orbit. At the beginning of this period, there is occultation at latitude 81°, at the end of the period the same effect 9° from the opposite pole.

With the configuration, there is at any one time one satellite between any point in the penumbral belt and the sun's disc. The area of the satellite is 144 km^2. The loss of solar power is

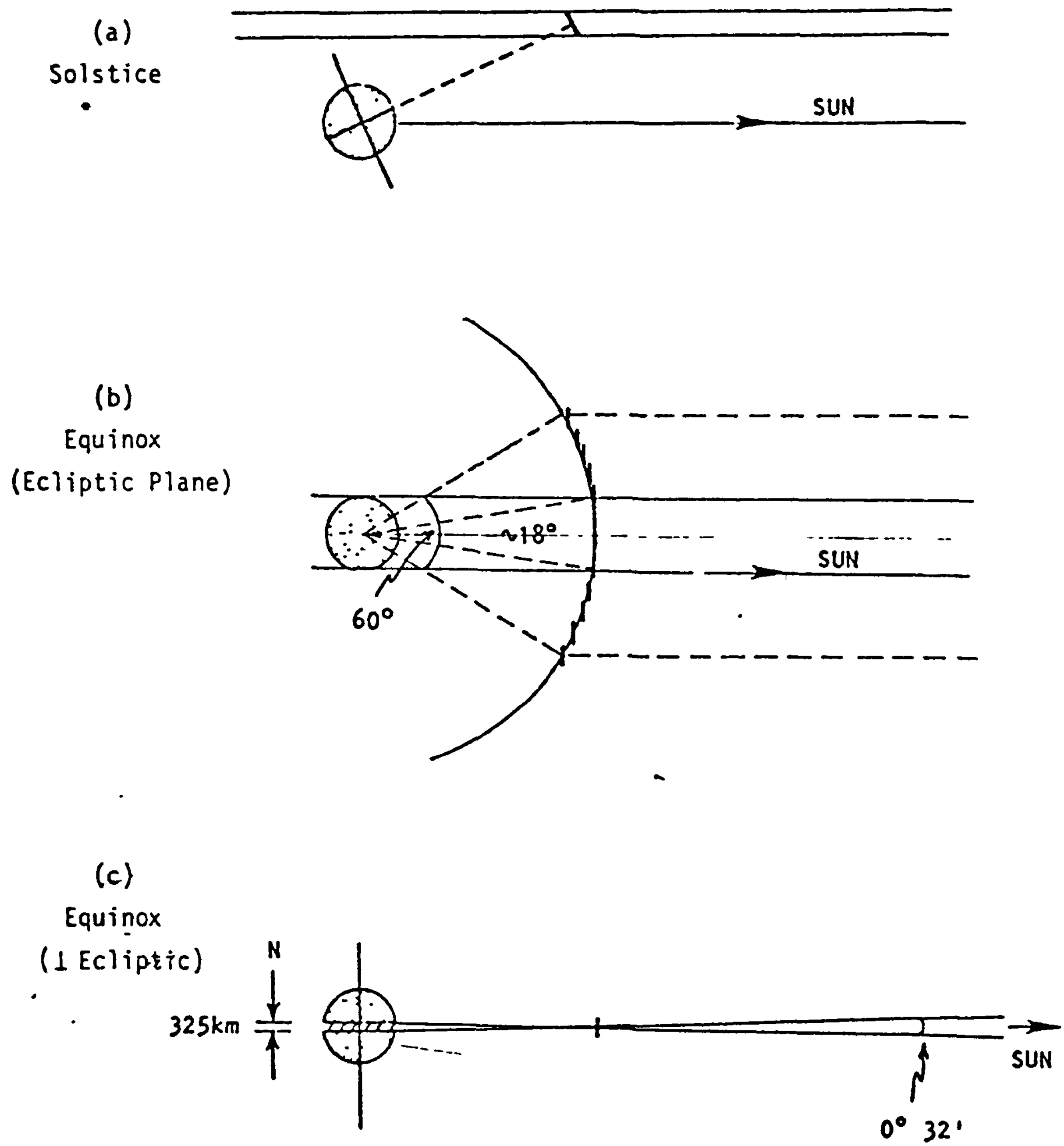


Fig. VII-A-6 Earth-Satellite Configuration

$$144/(3.5\times10^4)^2 \div \pi(4.65\times10^{-3})^2 = 0.00173$$

Approximate integration over the day shows that a fraction 7.6×10^{-4} of available solar power is lost in the penumbral belt.

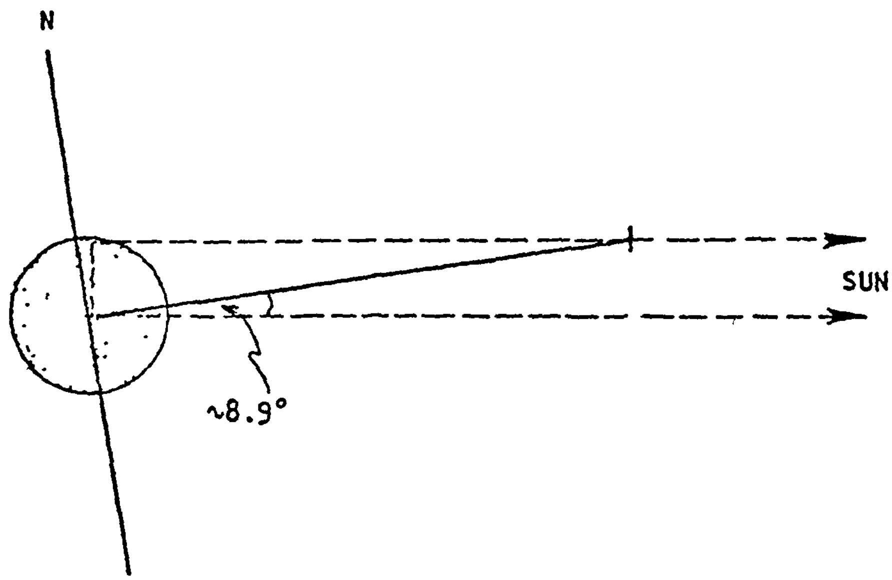
At latitude ϕ the width of the penumbral band at occultation is about 325/cos ϕ km, the fraction of available solar radiation removed at any location is the same as at the equator. The absolute loss of energy is the same, spread over the same area, but over a broader latitude band. The latitude of the center of the occulted belt is $\sim \cos^{-1}(6.5 \tan \delta)$.

The overall effect of occultation is that for about four hours around noon on two of about 80 days each year, the solar power outside the atmosphere at a point equatorward of 80° latitude is reduced by about 0.17 percent and rather less that 10 percent of this is released at the surface in the U.S.A. A steady decrease of 0.2 percent in the solar constant is about at the limit of detection by currently available methods, given integration periods of order one year. Detection of the same reduction on two days each year would call ofr integration times of order 100 years.

Global meteorological effects of such a reduction would be lost in the "noise" of weather and climate variation. The appropriate method of investigation of systematic effects of any change in amount or distribution of incoming radiation is the general circulation model of the atmosphere (G.C.M.). Existing GCM's do not approach the precision and resolution required to handle changes of order 0.2 percent solar constants over limited areas and period. There is reason to speculate that such a model can never be constructed: certainly one will not be available for many years. Current knowledge of atmospheric processes suggest that environmental effects of occultation will be so small as to be neither unequivocable detectable nor calculable. In these circumstances, it will not be possible either to affirm or deny that any observed "anomaly" is attributable to occultation.

Microwave Beam Description

The 2.45 GHz microwave beam used to transfer the energy collected in orbit to the earth's surface is discussed in Section 4. of NASA publication JSC-11568, Volume 2. Previous studies of microwave transmission through the ionosphere indicate that nonlinear interactions begin to occur at some threshold power density level around 23 mW cm^{-2}. The validity of this number needs to be well established because it has a large impact on the sizing and performance characteristic of the solar power system. The combination of this threshold level, an operating frequency of 2.45 GHz, a desired energy transfer of 5 GW, and the thermal limits described in the JSC report result in an antenna which has a diameter of approximately 10 km on the earth's surface. Latitude correction increases the major axis of the rectenna in a north/south direction. The microwave beam propagates through the atmosphere at an angle off-vertical slightly greater than the rectenna's latitude.



VII-A-7 Onset of Occultation at $\Delta \sim 8.9°$

Transmission of the earth's atmosphere at these frequencies is very efficient. The small amount of energy that is absorbed by the stratosphere and troposphere is negligible even if the beam power is substantially increased. The small amount of energy that is lost in the ionosphere presents some questions. A threshold level of approximately 23 mW cm^{-2} has been established to avoid nonlinear interactions with the ionosphere. This threshold has a very great influence on the size of the ground rectennas necessary to receive a fixed amount of energy from the orbiting satellites. It has been postulated that as this threshold level is approached heating will be high enough to reduce the electron/ion concentration. This "hole" will alter the ionosphere response to propagating radio frequencies and could disrupt HF, VHF communications systems, and VLF navigation systems due to the additional RFI and multipath degradations. It has been suggested that this altered ionospheric path should be examined for possible alterations in the beam intensity distribution that arrives at the rectenna surface. The alterations which will occur in the ionosphere and their deleterious effects should be the subject of continuing studies because of the strong role that this threshold limit has in setting the overall scale of the transmitting/receiving geometry. Significant reductions in overall systems costs might result if the energy density can be increased and/or the microwave frequency be increased.

Rectenna Description

The rectenna site is envisioned to be approximately 80,000 acres and located close to the user. The rectenna structure will cover between 30 percent and 40 percent of this area with the remainder being a buffer zone for the microwave energy density to decrease to a safe continuous power level. Several structural design approaches are being evaluated but all used in the present study utilize large reflective panels holding subassemblies which collect the microwave radiation and convert it to DC current. The reflectors in this case are envisioned to be expanded metal screen wire. Specifics of the design of these subelements depends on latitude, but the basic criteria is that they be far enough apart that they can easily reached for service/maintenance. The example calculated for Houston results in a structure of expanded metal panels 4.9 m long and 15 m on the hypotenuse and inclined at 36° placed end to end to produce long rows with the hypotenuse faces pointed in the direction of the satellites which serve the rectenna. The spacing between rows would be 6.4 m to allow access. Approximately 1000 rows would be needed for the rectenna which would have a major axis of $\sim$12 km. The rectenna presented in NASA JSC-11568 uses a very simple structure and no attempt has been made to optimize the structure as to concept, weight, or cost. One design option is to series connect all the microwave rectifying subelements to generate a very high DC voltage over the antenna. If this method is used then the very high voltages will require that those on the higher voltage end of the string be insulated from ground. Adopting this high voltage technique may have a marked influence on the design concept utilized.

Findings

Beam Propagation Effects

Absorption at 2.45 GHz is extremely small in the stratosphere and mesophere. Fractional absorption of the zenith path in a cloud-free atmosphere of a beam at about 2.5 GHz is about 0.01. About 1/10 of this occurs in the stratosphere and mesophere. The resultant mean heating rate for an SPS beam is about 10^{-2}°C per day. The mean heating rate due to absorption of solar radiation is of order 10° C per day. The heating rate corresponding to absorption of the maximum microwave power, roughly four times the average over the beam, is 2×10^{-3} of the local average solar heating rate. As in the thermosphere, there is no possibility of direct photochemical interaction. The effect of the beam on the physical state of the mesosphere/stratosphere is not detectable by known techniques. This would be true for a beam of double or triple power.

The heating of the troposphere by absorption of the microwave beam is of order 2×10^{-2}°C per day. Direct heating by absorption of solar radiation is of order 2°C per day on the average for the troposphere. In clear air the average effect of solar radiation is about 100 times that of the beam. The effect of the beam would be very difficult to separate from the noise of the solar effect due to normal atmospheric variability. The possible effect on atmospheric dynamics is neglibible. This would be true at doubled or tripled power. A tenfold power increase might justify reconsideration.

Atmospheric absorption per unit area of the earth's surface is independent of the latitude fo the site, (except for the climatic variation of water content with latitude). Relationships between convective, conductive, evaporative, and radiative processes in the atmosphere are complex.[16] Absorption in cloud is greater than absorption in the clear atmosphere. To assess the possibility that absorption of the microwave beam might interfere with natural processes in clouds it is convenient transform the additional absorption exclusively into a rate of evaporation of water. For the stratus cloud, this if found to be about 0.0015 g.m.$^{-3}$ day^{-1} over a height range of 3 km. In the absence of other processes, the cloud would be dispersed in about 20 days. This energy conversion rate is between 10^{-2} and 10^{-3} that associated with natural cloud-forming and dispersing processes. In the severe thunderstorm case, the peak power heating is sufficient to evaporate about 0.05 g.m.$^{-3}$ day^{-1} over a 10 km layer, equivalent to about 10^{-3} of the natural energy conversion rate during the lifetime of a large storm. Existing models of convective cloud are not sufficiently detailed and precise to handle perturbations of this magnitude. Any actual effects of this perturbation could not be detected in the presence of the natural variance of cloud and storm phenoma. Doubling or tripling beam power would not affect these conclusions.

Clean lower tropospheric air contains on average about 10 $\mu g\ m^{-3}$ of particles with median radius comparable with the wavelength of visible light, about 0.5 μm. In polluted atmosphere the loading may be ten times greater, with scale heights about 1 km. The mass loading per unit area of surface is 10^{-2} to 10^{-1} $g\ m^{-2}$. For 2.5 GHz radiation the particle radius is of order $5x10^{-6}$ the wavelength of the radiation. Scattering by the particles, even in heavily polluted atmospheres, is quite negligible. The particles in the clean air situations are predominantly sulphuric acid or ammonium sulphate solutions. Polluted atmospheres caused directly or indirectly by combustion processes contain larger numbers of these particles with the addition of carbon, metal oxides, silicates, etc. Such particles absorb as well as scatter solar energy. On occasions, over large areas of the Midwestern U.S.A. and Europe, five percent or more of incident solar energy is absorbed. There is little firm knowledge about the absroptive properties of these materials for microwaves. For silica and alumina the absorption coefficient at 3 GHz is very small. The abount of material (10^{-1} gm^{-2}) corresponds to a continuous screen only 2 to 5 μm thick. (Note that because there is no coherence in the interaction of radiation and the particles, this analogy, though reasonable for producing rough estimates of absorption, has no relevance to scattering and reflection.) Absorption of the 2.5 GHz radiation by atmospheric particles (other than water particles in cloud) will be negligible, both absolutely and in comparison with absorption of solar radiation. Effects on the atmosphere will not be detectable. Doubling or tripling the beam power will not affect this conclusion.

Blake et.al., (1970)[17] have calculated the relationship of microwave frequency to absorptivity as beam elevation angle is varied for an assumed oxygen and water vapor content troposphere. Bean et.al. (1970)[18] have published measurement results which relate absorption to height above the surface for several frequencies. Results indicate that microwave frequency could be increased without great increases in microwave absorption in the atmosphere. Preliminary results of some ongoing studies currently being performed have suggested the beam diffraction and refraction effects may produce slight intensity variations across the microwave beam as it propagates through the atmosphere, but no strong focussing effects are expected which would invalidate the foregoing conclusions.

Rectenna Effects

Consideration here is limited to possible effects on weather and climate, local and global. Ecological consequences, directly due to land disturbance and change of usage, and indirectly due to microclimate change, are to be expected but are not considered in detail. Climatic perturbation may be subdivided into "active" -resulting from the heat release consequent on collection and conversion inefficiencies, and "passive" - resulting from changes in the surface radiation balance, consequent on land use change and the rectenna structure.

Allowing for residential, commercial and one-third of the total per capita transportation usage, suburban power consumption in the U.S.A. in 1974 was about 5 KW per person.[19] The rectenna's influence on weather and climate should be similar to that of a dormitory suburb of 150,000 people. It is important to consider this environmental effect in the context of the power-consumption scenario used in designing the solar power system. THe 750 MW dissipated at the rectenna site is the "waste heat" of a 5 GW power plant. The remainder of the 5 GW is released away from the rectenna site, most of it in areas with a higher surface density of energy conversion. The most marked environmental effects of the SPS will occur in the areas of usage. This does not make it any less important to investigate the environmental effects of the rectenna sites, but their significance should be judged in the context of the 2025 population and environment scenario, including the consequences of using alternative power sources. The required environmental impact is on the world of 2025, not that of 1975.

It will be assumed that the excess heat is absorbed in the lower portion of the atmosphere, which is in contact with the earth. Judging by the surface roughness exhibited by the rectenna arrays, a depth of 100 m is a reasonable depth to assume as a sink for all of the excess heat. It is necessary to compute the amount of temperature rise in a cylinder of 5 km radius and 100 m height. It is reasonable to assume 900 mb (about 3,000 ft. altitude), 0°C, and dry air. It is further assumed that the heating takes place at constant pressure and all of the energy is used to increase the air temperature (no work is done). The following equation applies:

$$\Delta T = \frac{dH}{30\pi\rho r C_p v h}$$

where ΔT is the temperature rise (°C)

dH is the heat added (750 MW = 1.075×10^{10} cal min^{-1})

ρ is air density (1148 g m^{-3} at 900 mb, 0°C)

r is the radius of the array (5,000 m)

C_p is the specific heat of iar at constant pressure (0.24 cal g^{-1}C^{-1}

v is wind speed (m s^{-1})

h is the mixing depth (100 m)

This simplifies to

$$\Delta T = \frac{.83}{v}$$

Solving this for various wind speeds indicates the maximum amount of temperature rise expected in the lowest 100 m of the atmosphere as it passes over the rectenna. These values are plotted in Figure VII-A-8 . The corresponding curve for twice as much (1500 MW) heat dissipation is also shown.

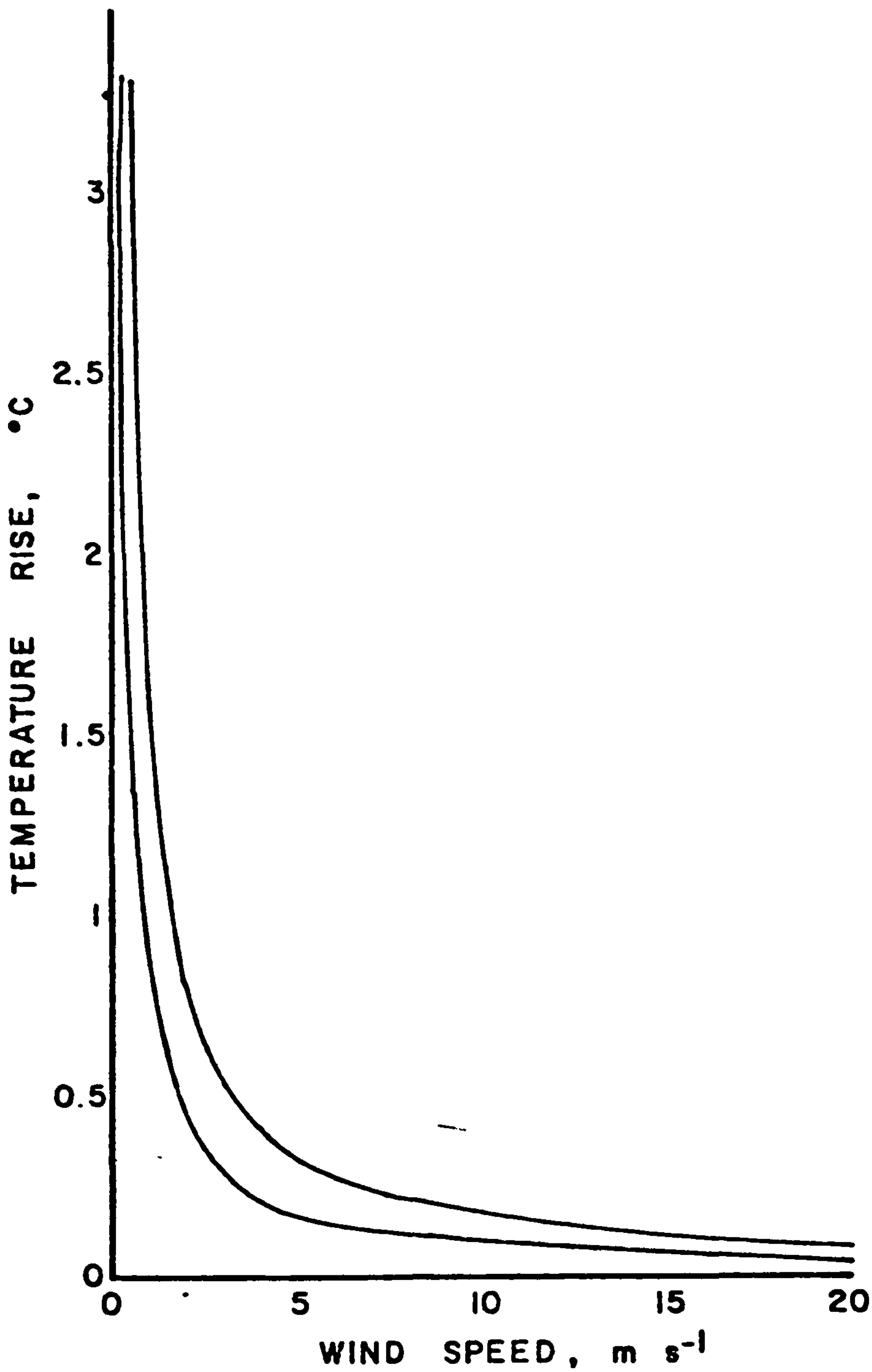


Figure VII-A-8 Temperature rise vs wind speed in the lowest 100 m of air crossing a rectenna site.

These data indicate that heating drops very rapidly as wind speed increases to ~4 m s^{-1} and is of no consequence at faster speeds. The heating for slower speeds is possible significant.

The amount of temperature rise is inversely proportional to the mixing depth. As the air near the surface gets warmer, it tends to rise and cool by adiabatic expansion. This increases the mixing depth and automatically reduces the amount of temperature rise. Under stable conditions, as on a clear, calm night, much more heating is required to get an increase of mixing depth than in the middle of a sunny, windy day, where unstable conditions prevail. Thus, the maximum temperature rise would occur under calm, stable conditions. These conditions are most likely to occur in a valley on a clear, calm night.

On clear, calm nights, it is possible to get an inversion of as much as 20°C per 100 m. Assuming a wind speed of 0.25 m s^{-1}, we can solve equation (1) with ΔT and h as dependent variables, as follows:

$$\Delta T = \frac{271}{h}$$

But, since the adiabatic lapse rate, which will be present in the heated air is

$$\Delta T = .010h,$$

we can solve simultaneously the mixing depth and temperature by combining equations (3) and (4). This gives ΔT = 1.65°C and h = 164 m. For the 1500 MW waste heat case, this would be ΔT = 3.3°C and h = 328 m. This is the maximum heat island effect under almost calm conditions.

Standard methods of computing the dispersion of pollutant emissions provide an alternative computation of likely temperature rise. Using the "Gaussian plume" model with parameters recommended by the Environmental Protection Agency yields results consistene with the preceeding. In addition, it forecasts differential temperatures downwind from the rectenna. Considerably more detailed and complete model simulations need to be performed before a confident prediction could be made regarding impact the rectenna could have for a range of atmospheric conditions.

From a meteorological standpoint, the rectenna as presently conceived does not appear "rough" in the same sense that topographic features or tall man-made buildings might aggravate turbulence flow near the ground. The roughness of the rectenna could possible be important when considering the structural design safety factors and influences in and around the structures per se.

The rectennas could be located at almost any suitable location near the user in the continental United States. It has been concluded that this is primarily a function of convenience and suitability from the specific rectenna element structural design concept adopted. It may be found that a south facing mountain range front would offer some natural

advantages in that the rectenna might be smaller if located there. If the rectenna were on the windward side of a mountain range on such a slope, the waste heat from the rectenna might exaggerate the normal uplife of air crossing such a topographic feature. A site located in a warm humid climate might also increase clouds and rain showers in the usually unstable atmospheric conditions present. Any such effect would be difficult to demonstrate statistically because of the usual rainfall variability in such locations.

The impact that the rectenna will have due to modification of the normal albedo to the absorption of solar radiation and the emission of thermal energy will probably be the greatest effect that the rectenna site will have on the site selected. These factors also have some degree of control from the standpoint of design, materials for construction, and preparation and utilization of the underlying soil.

Other Effects

The orbit dynamics disucssion in Section 2.2 described a very small decrease in the amount of solar energy available at the earth's surface. Changes in the earth's weather due to this occultation will not be detectable.

The change in land use over to a rectenna site may produce changes in the ratio between energy losses to water evaporation and energy losses through convective processes which would affect local temperature, humidity, and the frequency of fog formation (as do the changes which follow urban development). There is the possibility of an effect on cloud populations. It is, therefore, necessary to consider the use of the ground below the rectenna elements. The natural evaporative pattern at the site area could probably be matched by a suitably chosen crop growing in the reduced light intensity below the rectenna elements. At the center of the site in the region of maximum microwave power, the flux of uncollected microwave radiation will be of order 10 Wm^{-2}, which is the full intensity at the nominal edge of the beam, and one tenth the limiting power for exposure of human subjects under current practice in the U.S.A.

The major discussion has been in terms of a 5 GW beam of 10 km diameter. With this system, the mean power dissipation over a site in the contiguous U.S. is at maximum about 10 percent of the natural net radiative flux. The site area is 100-105 km^2. In 1971 the estimate for a built-up area of the city of Cincinnati was a power conversion rate of 26 Wm^{-2}, 25 percent of the natural surface radiation balance. For 60 km^2 of Manhattan Island, the estimate was 630 Wm^{-2}, seven times the natural radiation balance. The climate of Manhattan Island and Cincinnati differs from that of their immediate surroundings but (apart from the irrelevant matter of air quality) no extensive climatic influence on the surroundings themselves has been noted. It is clear that from the point of view of climatic effects alone, the proposed dissipation at the rectenna sites could be greatly increased without disaster in the surroundings. Conventional fossil fuel plants producing 5 GW electrical power within the rectenna site would dissipate

7.5 GW "waste heat", ten times that of the rectenna dissipation considered. It would, however, be necessary to examine carefully the climatic effects of such large dissipation rates, (see recommendations). Contemporary experience of the effect of cities suggests that they would be tolerable but perhaps not desirable.

Rectenna Construction

In adapting the rectenna site to the environment, man has an opportunity to control the solar abosrption and thermal reradiation of energy from this site. The extreme case would be to deliberately cause it to absorb the maximum amount of solar radiation in the daytime and insolate against the loss of this energy during the night. The handling of the energy so it is trapped excites the imagination. It could be utilized directly to heat air in and around the rectenna or possibly be piped off, sotred in the soil, or be exported to another adjacent site to be utilized for constructive purposes. It might also be a solar energy converter if it is located in an area having little cloud cover. At the other extreme it could be made to reflect the majority of solar radiation during the day and emit the maximum amount of thermal energy and actually obtain a cold island effect on the earth's surface. At this time it is not clear what benefits could be achieved by controlling the radiative properties (passive features) of this facility. It is obvious that multi-functional utilization of such a large area as occupied by these rectenna sites is desirable. Consideration of these other activities is beyond the scope of this report, but when these considerations are made a farily detailed mesoscale weather model should be available for evaluating proposed designs.

Conclusions

Weather and climatic effects of the SPS system as outlined in JSC-11568 will be very small. If the power density of the beam is limited to about 250 Wm^{-2}, no feature of the entire system has been identified in which possible weather or climate modification is a significant constraint. Power dissipation at a rectenna site is around 10 percent of the average "natural" energy conversion at the surface in the U.S.A. and is considerably less that that at present occurring in many cities of area comparable with a site. Changes in "natural" energy conversion consequent on albedo changes will be comparable with the power dissipation and there are possibilities of compensation by variation of construction details and surface finish. For this reason, there is little meteorological input into the question of choice of site, geographical, topographical and climatic, within the contiguous U.S.A. Engineering considerations and the direct ecological consequences of construction, operation and maintenance will carry much more weight.

If increase in power density of the beam by a factor of five or more is contemplated, there will be no possibility of "passive" compensation for dissipation by adjusting the radiative properties of the artificial surfaces. Dissipation at the site will be comparable with

high-density population centers with some industrial activity. Meteorological considerations will become a factor in site choice, but still probably not a decisive one.

Passage of the microwave beam through the mesosphere, stratosphere and troposphere will not produce disturbances of meteorological consequence. This would be true at power densities greater by a factor of ten than that porposed, but in this case absorption in heavy rain might become an undesirable economic factor to be considered with other economic factors in choice of sites. The SPS system has no specific features which render it likely to produce regional climatic modification (i.e., over the U.S.A. as a whole). This cannot be said so confidently of the general expansion of energy conversion which the SPS is designed to meet. The high thermodynamic efficiency of the surface components of the SPS gives it a definite advantage over fossil fuel and nuclear power generation from the point of view of climate modification.

Recommendations

Design alternatives for the SPS rectenna are available to control the capture of incident solar radiation. Some of these designs will dissipate large amounts of heat into the ambient air. These high heat dissipation designs along with the thermal and momentum effects of replacing the natural terrain with the rectenna, could have a substantial influence on local weather. In view of this it is recommended that plans be made to (1) develop the capability to mathematically model proposed designs and predict how they may affect various climatological/topographic situations at rectenna sites and (2) confirm the results, along with other aspects of the facility/installation, by building a prototype rectenna section and instrument it to measure the response to the solar/thermal radiation fields.

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VII. ENVIRONMENTAL FACTORS

A. Konradi
S.-Y. SU

B. IN-SPACE OPERATIONS

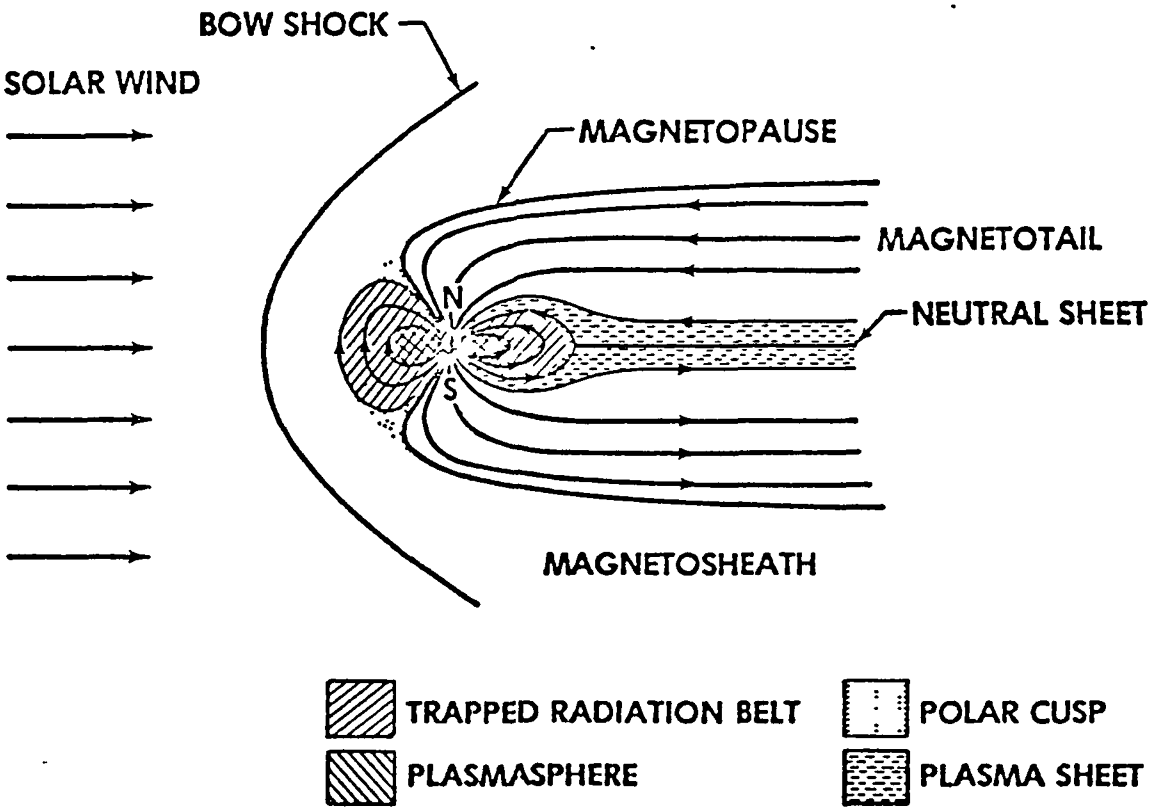
1. Radiation

a. Environmental Description: Description of the Plasma Environment at Geosynchronous Altitude.

Introduction: The sun is known to eject in a radial direction a continous stream of tenuous plasma consisting predominantly of ionized hydrogen gas. This plasma is called the solar wind and has a flow velocity about 400 km/sec and a density of the order of 10 ions/cm^3 near the earth's orbit. When the solar wind particles impinge on the earth's magnetic field, the particle kinetic pressure is high enough to effectively bend the field lines. In turn the field lines deflect the incident charged particles by exerting a force on them (the Lorenz force). A cavity that excludes all the impinging plasma particles, called the magnetosphere, is thus created. Figure VII-B-1 shows the noon-midnight meridian profile of the earth's magnetosphere. The geomagnetic field lines are seen to be distored greatly from a dipole field such that on the sunward side they no longer extend to infinity but are compressed. On the other hand, the field lines are stretched out along the solar wind flow direction in the night-side, forming the so-called magnetotail.

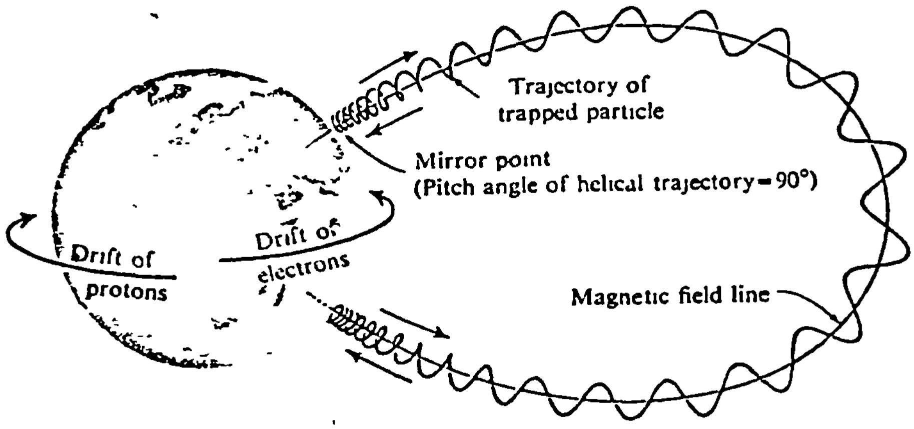
From hydrodynamics we know that a detached shock wave will be formed in front of a blunt object obstructing a fluid flowing at hypersonic speed. In like fashion, a detached shock is found in front of the magnetosphere since the solar wind flows at a velocity considered to be hypersonic with respect to the propagation speed of hydromagnetic disturbances along the magnetic field lines (Alfven speed), which is about 35 km/sec.

In the inner magnetosphere where the geomagnetic field lines do not deviate too much from the dipole field configuration, a charged particle will simultaneously execute three different kinds of motion, namely, a gyration around the magnetic field line, a latitudinal bounce motion along the field line, and a longitudinal drift motion around the earth. The particle trajectory in a magnetic dipole field is sketched in figure VII-B-2. Those electrons and ions that are not lost in collision with the earth's atmospheric neutral particles during the bounce motion and are able to make a complete drift motion around the earth, constitute the so-called trapped radiation. Satellite observations of long time averaged equatorial omni-directional electron and proton flux intensities measured above several different energy thresholds in the trapped radiation region are shown in figures VII-B-3 and VII-B-4, respectively. The horizontal axis in each figure is the approximate distance of the assumed undistored dipole field line at its intersection with the equatorial plane, L, in units of earth radii, R_E. The radial distance of the trapped radiation belt in the figures is shown up to L = 12 R_E which is close to the average stand-off distance of the magnetosphere in the sunward direction. A Geo-Synchronous satellite is located at L = 6.6 R_E .



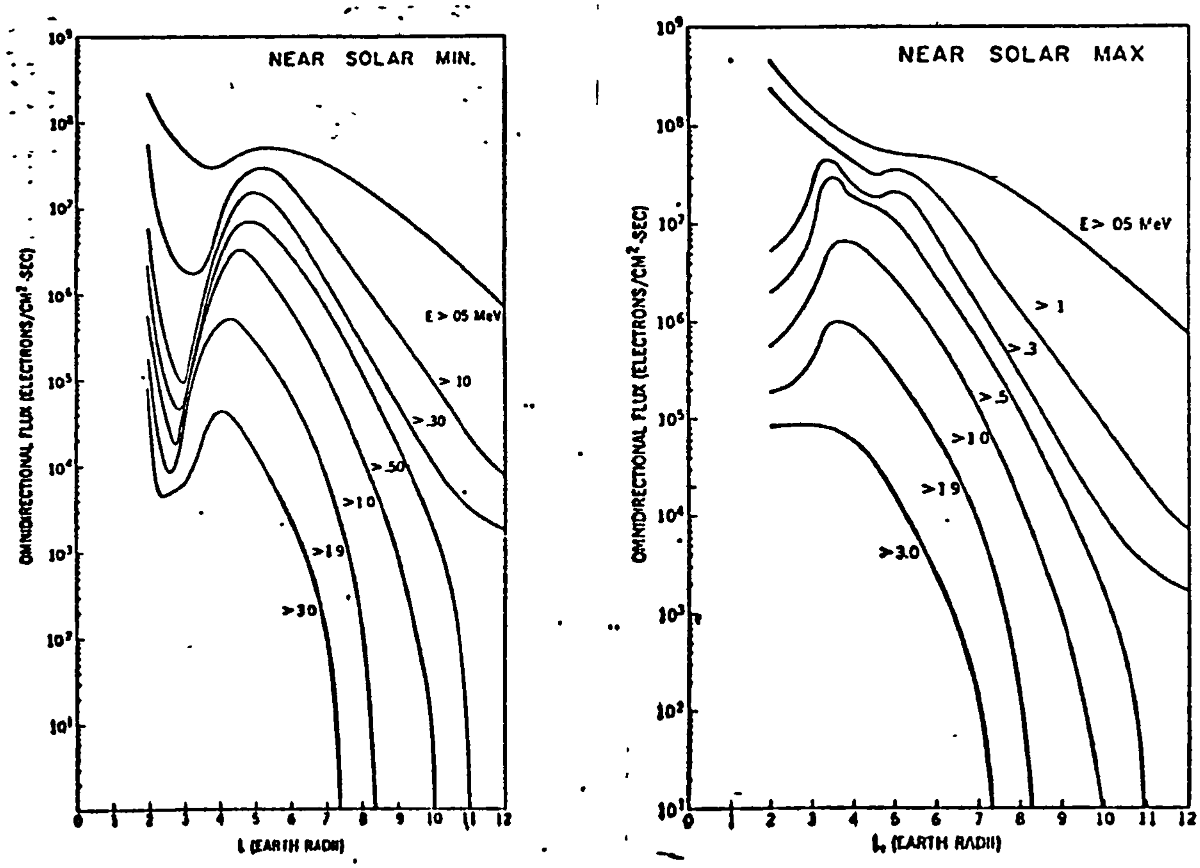
The profile of the earth magnetosphere in the plane containing the earth dipole axis. A bow shock is created in front of the magnetosphere as the magnetosphere obstructs the solar wind flow which is streaming away from the sun. The geomagnetic field lines are greatly distored by the solar wind impingement such that they are compressed in the sunward direction and are stretched out in the anti-sunward direction. Regions of large charged particle population observed inside the magnetosphere are indicated in the figure.

Figure VII-B-1



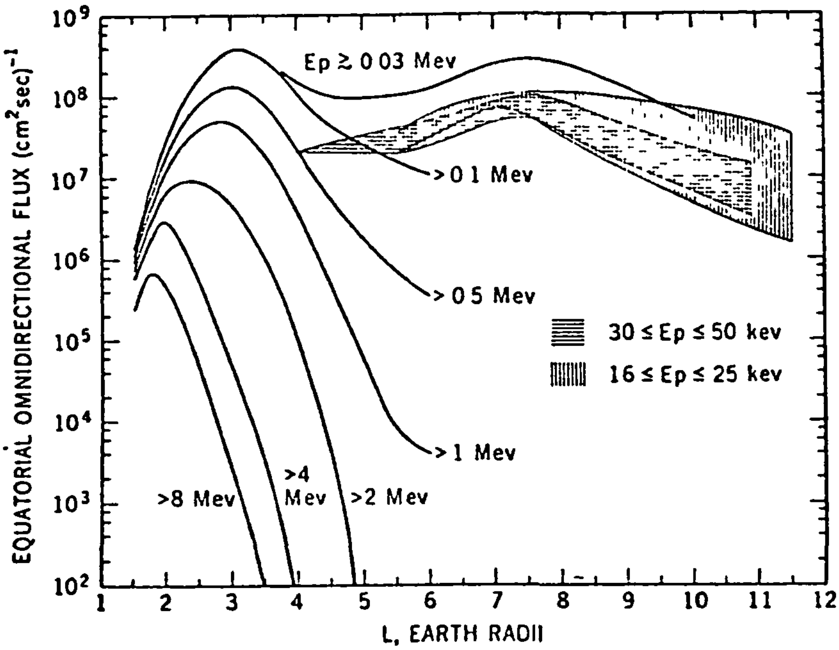
Motion of a charged particle in the earth's dipole field. The motion consists of (1) gyration around the field line, (2) latitudinal bounce motion back and forth along a field from one hemisphere to the other, and (3) longitudinal drift motion around the earth with electrons drifting east and protons west. (after W. Hess, 1970).

Figure VII-B-2



Time averaged radial profiles of the omnidirectional electron flux intensities with electron energies above several energy thresholds. The data were obtained near the earth's magnetic equatorial plane at all available longitudes and in the years close to solar minimum as shown in (a) or close to solar maximum in (b) (after D. J. Williams, 1972).

Figure VII-B-3



Time averaged radial profile of the integral equatorial omnidirectional proton flux intensities for several energy thresholds. The two shaded areas represent protons observed in two limited energy passbands, respectively. The Ep $\geq$ 0.03 Mev curve is an estimate by using the 30 - 50 Kev and the > 100 Kev values (after D. J. Williams, 1972).

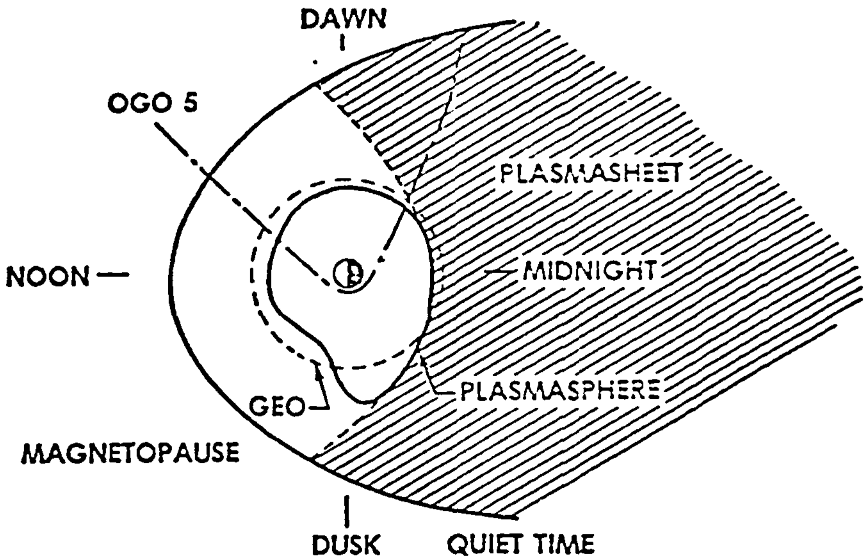
Figure VII-B-4

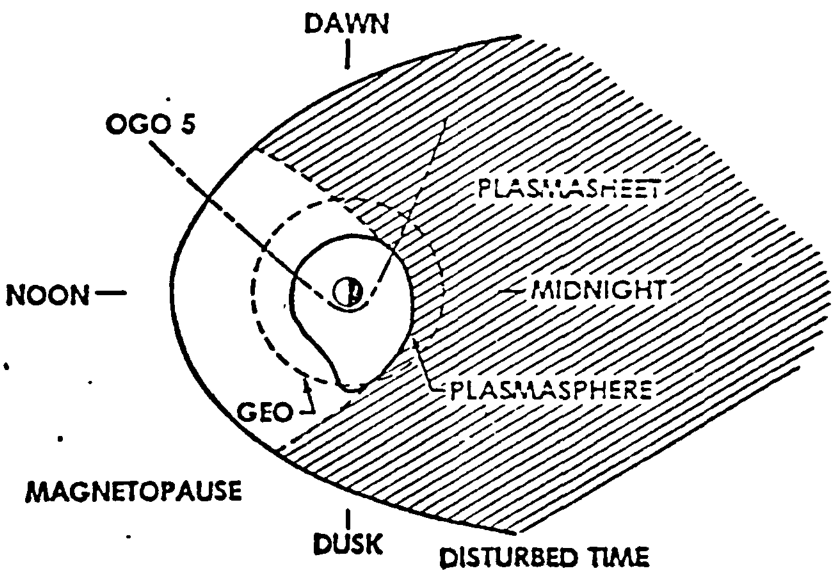
Besides the high energy particles trapped in the magnetosphere, there are also large concentrations of plasma inside the plasmasphere near the earth, with energy between .1 and 10 ev, and large concentrations of plasma, with energy of ~500 ev, in the plasma sheet located in the magnetotail (see figure VII-B-1). The plasma sheet has a thickness of ~4 R_E and its center is located at the neutral sheet, an interface between two anti-parallel magnetic field regions in the magnetotail. The earthward extension of the plasma sheet along the geomagnetic field lines that are stretched out into the magnetotail reaches down to the auroral region (geomagnetic latitude 60° - 67°, L = 4 - 6.6 R_E). The equatorial extension of the plasma sheet in the earthward direction is shown in figure VII-B-5. Also shown in the figure is the shape of the plasmasphere in the equatorial plane.

The azimuthal coordinate to which locations in the magnetosphere in the equatorial plane are referenced is called local time (LT). Since the shape of the magnetosphere is determined by the interaction of the solar wind with the earth's magnetic field, local time forms a convenient angular coordinate. Thus midnight, dawn, noon, and dusk correspond to local times of 0, 6, 12, and 18 hours respectively.

Dynamic Behavior of the Plasmasphere: In the equatorial plane the inner edge of the plasma sheet coincides with the night-side boundary of the plasmasphere. The cross section of the plasmasphere in the equatorial plane is seen to resemble the cross section of a doughnut with a bulge. The orientation of the plasmasphere is more-or-less fixed in the magnetosphere. But the size of the plasmasphere changes in accordance with geomagnetic activity. During a geomagnetically quiet time a geosynchronous orbiting satellite can penetrate into the plasmasphere in the dark sector of the magnetosphere, and stay inside the plasmasphere for several hours as shown in figure VII-B-5 (a). The plasma density inside the plasmasphere decreases monotonically with L and at GEO may be 10-1000 particles/cm^3. By contrast, the density of high energy particles in the trapped radiation belt or in the plasma sheet is about 1 particle/cm^3. Thus the geosynchronous satellite will frequently encounter two drastically different plasma environments near the dusk meridian. Figure VII-B-6 shows radial profiles of the plasma concentration observed by an elliptically orbiting satellite. Different degrees of geomagnetic activity are indicated by the planetary magnetic index Kp. It should be noted that this observed radial density profile is only appicable along the satellite trajectory shown in figure VII-B-5. The radial variation of the plasma density at other local times of the magnetosphere should be scaled according to the shape of the plasmasphere shown in figure VII-B-5. Clearly the size of the plasmasphere expands during quiet times ($Kp<1^+$) and contracts as the geomagnetic activity increase (Kp~4-5).

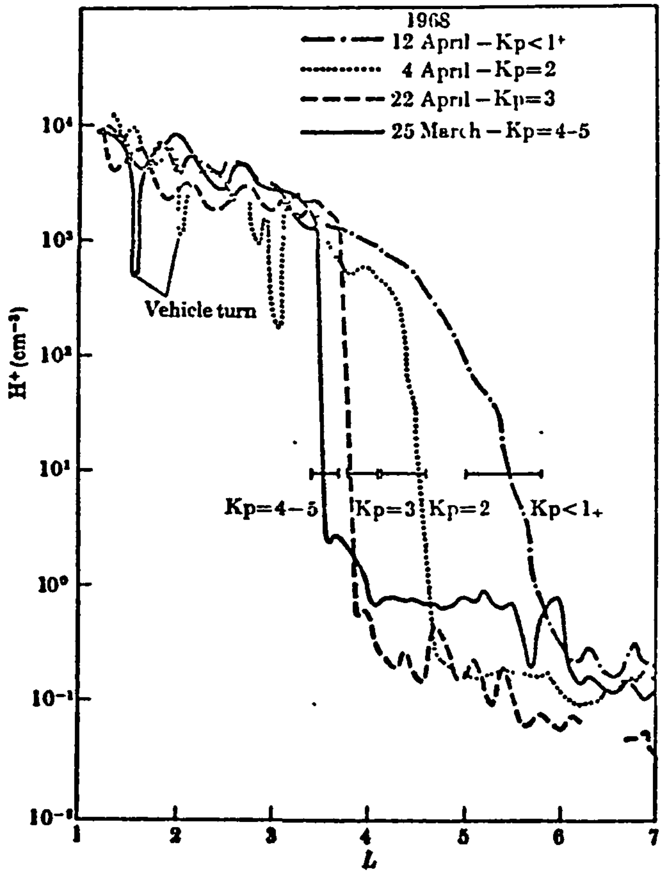
The formation of the plasmasphere can be understood from the longitudinal drift motion of the very low energy particles. In addition to the magnetic field a quasi-steady state electric field, perpendicular to the magnetic field, also exists within the magnetosphere. The electric field is composed of an electric field generated by the solar-wind interaction with





Equatorial profile of the plasmasphere and the plasma sheet (hatched) regions. Note that the intrusion of the plasmasheet particles toward the earth and the shrinkage in the size of the plasmasphere during geomagnetically disturbed times compared with the quiet times. The relative position of the plasmasheet and the plasmasphere with respect to a GEO satellite orbit is also shown in the figure. The OGO 5 satellite trajectory through which a radial profile of plasmasphere particle density was measured is also indicated.

Figure VII-B-5



The density profiles of the H^+ ions as functions of radial distance L during different geomagnetic conditions observed along OGO 5 satellite trajectory shown in Figure 5. Note that an extremely large density gradient exists at the boundary of the plasmasphere. The observation clearly indicates that the size of plasmasphere expands during quiet times ($Kp < 1^+$) and contracts as geomagnetic activity increases ($Kp = 4\text{-}5$) (after Chappel, Hannis and Sharp, 1970).

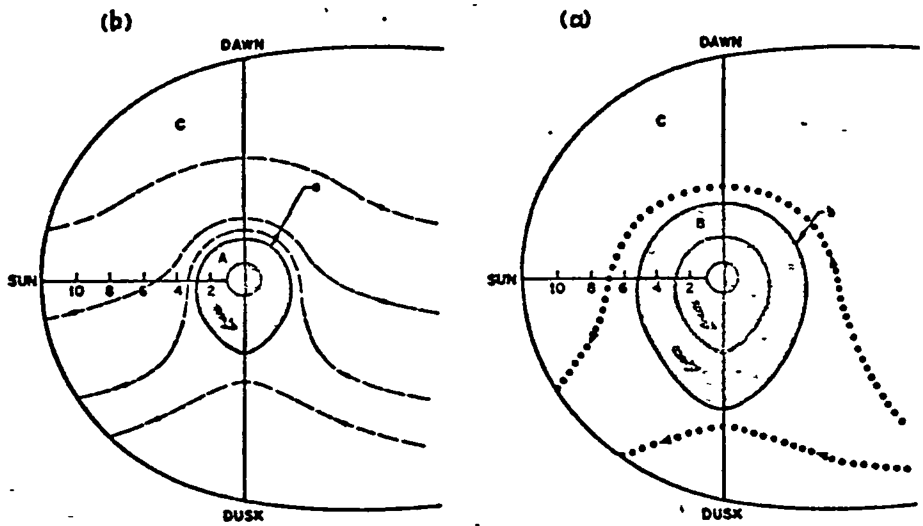
Figure VII-B-6

the magnetosphere and radially directed electric field induced from the motion of the geomagnetic field lines due to the rotation of the earth with respect to the magnetosphere. Figures VII-B-7 (a) and VII-B-7 (b) show the drift trajectories of the low energy particle during a geomagnetically quiet time (low Kp value) representative of a small electric field and during a geomagnetically active period (high Kp value) representative of a stronger electric field, respectively. The plasmasphere is then defined as the region where the very low energy particle drift paths are closed around the earth as shown in the figure. The size of plasmasphere is seen to be larger for a small electric field during the quiet time and becomes smaller for a larger electric field during the active period. The change in size of the plasmasphere is due to the fact that some particle drift paths which are originally closed become open when the electric field increases during geomagnetically active period. These open trajectory particles then drift away and out of the magnetosphere so that the plasmasphere becomes smaller.

During the geomagnetically active period at the onset of a magnetospheric substorm a large enhancement of energetic particle flux intensity will suddenly occur along the interface between the plasmaspheric boundary and the inner edge of the plasma sheet. The next two sections shall be devoted to description of such phenomena.

Description of Event Sequence during a Magnetospheric Substorm: A magnetospheric substorm involves a release of energy stored in the magnetosphere from the solar wind interaction with the magnetosphere. The mechanism required to trigger the energy releasing process is not completely known at the present time. It is, however, thought that the energy releasing process is nothing but a process to maintain the dynamic equilibrium of the magnetosphere in the solar wind interaction with the magnetosphere: As more and more solar wind kinetic energy is converted and stored in the form of electric and magnetic energy inside the magnetosphere, the magnetosphere becomes overloaded in energy so that an instability occurs which causes magnetic field energy to be converted into the energy of plasma particles. Eventually the heated plasma particles dump their energy into the earth's atmosphere which is dissipated away as heat. As long as the sloar wind keeps blowing against the earth's magnetic field, the cycle of slow but steady acquisition of energy and then the sudden energy release will keep repeating itself in the magnetosphere.

An analogue of the magnetospheric substorm in the earth atmosphere may be considered the lightening discharge of a thundercloud. When the upward moving warm moist air collides with the downward moving cold dry air, friction causes a separation of electric charge inside the cloud. This charge separation process results in a net negative electric charge in the lower part of the thundercloud and a positive charge in the in the upper part of the cloud. As more and more charge is accumulated, the electric potential difference between the upper and lower parts of cloud or between the lower part of the cloud and the earth keeps increasing. When the potential build-up reaches a certain point, such that the insulation effect of the air between the two separated charge clouds or between the



The formation of plasmasphere from a theoretical calculation of the drift trajectories of very low energy particles in a model magnetosphere. The shaded region where the particle trajectories are closed around the earth represents the plasmasphere. The size of the plasmasphere in (a) is larger when the quasi-steady state electric field is relatively smaller during a geomagnetically quiet time; in (b) is smaller when the electric field increases during an active period (after Chappel, Harris and Sharp, 1971).

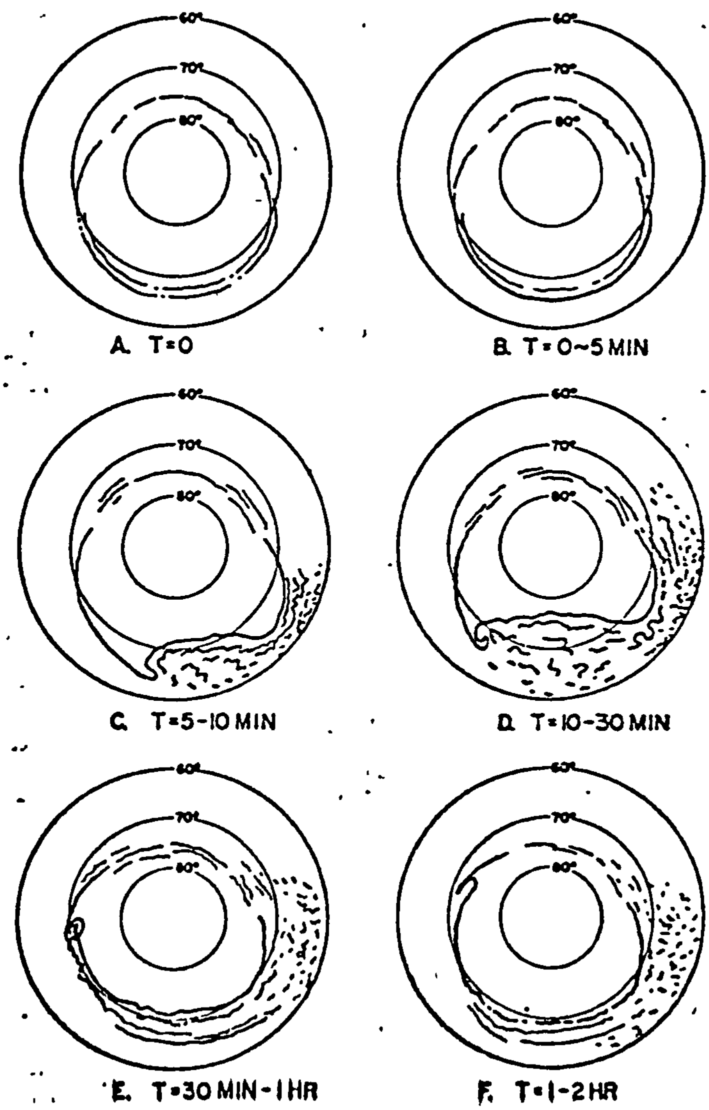
Figure VII-B-7

thundercloud and the ground breaks down a sudden discharge process occurs (lightening stroke) between them neutralizing the charge.

The sequence of slow build-up of energy (or charge) accompanied by a sudden release of the accumulated energy (or charge) is analogous in both the magnetospheric substorm energy releasing process and the atmospheric lightening discharge process.

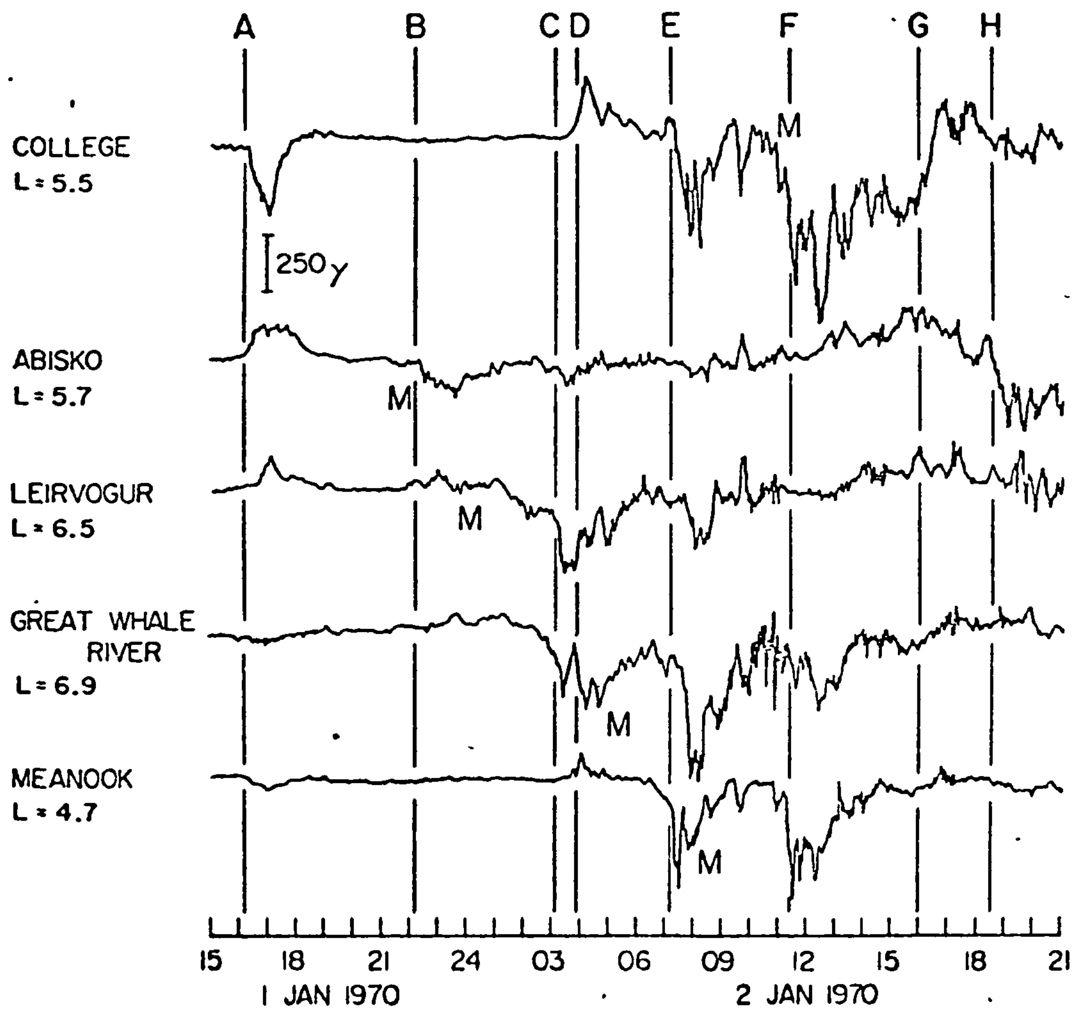
The magnetospheric substorm is best understood through its manifestation in the auroral substorm and in the polar magnetic substorm. Figure VII-B-8 shows the schematic drawings of a typical development of an auroral substorm in a geomagnetic polar projection where the sun is at the top of the page. A pre-existing quiet, arc-like pattern of aurora exists during the period prior to the substorm onset at time T = 0. For a few minutes following the onset, the substorm is in the expansive phase (T = 0-5 minutes) during which there is a brightening or sudden formation of new auroras near the midnight meridian, followed by a rapid poleward motion. This motion results in a bulge around the midnight sector wherein the so-called auroral breadup occurs (T = 5-10 minutes). As the auroral substorm progresses, the bulge expands in all directions (T = 10-30 minutes). In the evening side of the expanding bulge, a large-scale folding appears which travels rapidly westward along the arc, called, the westward traveling surge. In the morning side of the bulge, arcs disintegrate into patches which drift eastward. When the expanding bulge attains its highest latitude, the recovery phase of the substorm begins (T = 30-60 minutes). The expanded bulge then starts to contract. The westward traveling surge may continue a westward motion and eventually degenerate into irregular bands. The eastward drifting patches on the morning side remain until the end of the recovery phase (T = 1-2 hour). At the end of the substorm, the auroral situation will be similar to that just before the onset of the substorm. During geomagnetically active periods the cycle of growth and decay of the auroral substorm can occur repeatedly many times in a 24-hour period in the night-side magnetosphere.

During the auroral substorm, an intense electric current in the ionospheric E region is generated along the auroral oval, where the visible auroras are observed. This concentrated electric current called the auroral electrojet, can cause intense geomagnetic disturbances to be recorded on the magnetograms at ground stations near the auroral zone. Figure VII-B-9 shows an example of the horizontal magnetic field variations of five ground stations recorded around January 2, 1970. The horizontal time scale used in the figure is called universal time (UT) which is same as the Greenwich Mean Time. The local midnight at each station is marked with the letter M. The substorm onset is indicated by a sharp decrease of the horizontal field component on the magnetogram from a station near local midnight. The field recovers back to its original value at the end of the substorm. At least 8 substorms (indicated by Letter A to H) occurred during the period shown in figure VII-B-9.



Schematic diagrams to show the development of the aurora during a typical auroral substorm projected in the northern geomagnetic polar region. The sun is located at the top of each diagram. Time T= 0 is the reference time for the quiet period. Time T= 0-5 Min is the beginning of the expansive phase of an auroral substorm, while time T= 30 Min-1 hr. indicates the beginning of the recovery phase (after Akasofu, 1969).

Figure VII-B-8



The variations of the horizontal component of the geomagnetic field from five ground stations near the auroral zone. The radial distance of the field line passing through each station and intersecting the equatorial plane is also indicated by the value L. The local midnight of each station is indicated by the letter M. A sharp decrease in field strength from the ground station near local midnight is the indication of a substorm onset (letter A through H) (after DeForest and McIlwain, 1971).

Figure VII-B-9

Encounter of the Substorm Injected Protons and Electrons by a Geosynchronous Satellite: As mentioned earlier, the magnetospheric substorm is a process that converts the energy stored in the electric and magnetic fields into particle energy. Therefore, a particle detector onboard a spacecraft should detect a large ehhancement of particle flux intensity when the spacecraft encounters accelerated plasma particles during substorms. Figure VII-B-10 shows an example of such observation of high intensity proton and electron fluxes by a geosynchronous orbiting satellite, ATS-6, located at 94° W longitude. Plotted in the figure are the differential number flux intensities of protons or electrons versus the universal time at the spacecraft location. The local time of the spacecraft in the magnetosphere is LT = UT-6 hours. The differential number flux intensity is the particle flux intensity detected by a detector at a particular particle energy threshold. Only protons and electrons at energies E = 100, 1000, 10000, and 50000 ev are plotted in the figure. The overall particle observation for the day 201 of 1974 (20 July 1974) indicates that the electron fluxes have a greater variation than the proton fluxes. The sharp increases in electron flux intensities for various energy channels from 0300 to 0630 UT are associated with the encounter of the newly energized particles during substorm. For the purpose of identifying substorms from the flux increases observed at GEO a different display method has been shown to be more convenient. This display is known as the spectrogram and it shows the differential energy flux intensity displayed as a gray code versus time and non-linear energy scale as the x and y coordinates, respectively. White indicates the highest and black the lowest flux intensities. An example of the spectrogram for the same day as shown in figure VII-B-10 is displayed in figure VII-B-11. Although the spectrogram does not immediately reveal the actual flux levels observed, it does dramatically indicate the encounters with high intensity particle fluxes. For example, figure VII-B-11 shows that there are two clear white vertical streaks occurring simultaneously for both electrons and protons at 0440 UT and at 0630 UT, respectively. These are the signatures of substorms occurring at the position of the satellite and can be used to identify the substorm onset. There may be other substorm onsets occurring between the two mentioned substorms. However, they are not identified as easily as the two substorms in figure VII-B-11 without examining the spectrogram on an expanded time scale.

Other white cloud streaks are noticed in figure VII-B-11. These are signatures of substorms which occurred at places other than the location of the satellite. During a substorm particles are injected into a limited region of the magnetosphere and immediately begin to drift in azimuth as a result of electric fields and a non-homogeneous magnetic field. The drift velocity is roughly proportional to the particle's energy and thus a satellite encountering substorm injected particles would firtst see those of highest energy with the lower energies appearing at later times. This explains why the white cloud streaks in figure VII-B-11 are observed at high energy first and then move progressively toward lower energies.

An extensive study of spectrograms reveals that the energization of the plasma cloud during substorms occurs in a region which coincides with the spiral boundary of the doughnut shaped plasmasphere in the

AURORAL AND MAGNETOSPHERIC PHYSICS PROGRAM
NASA-Lyndon B. Johnson Space Center

DATE	NOTE NO.	PAGE

SUBJECT
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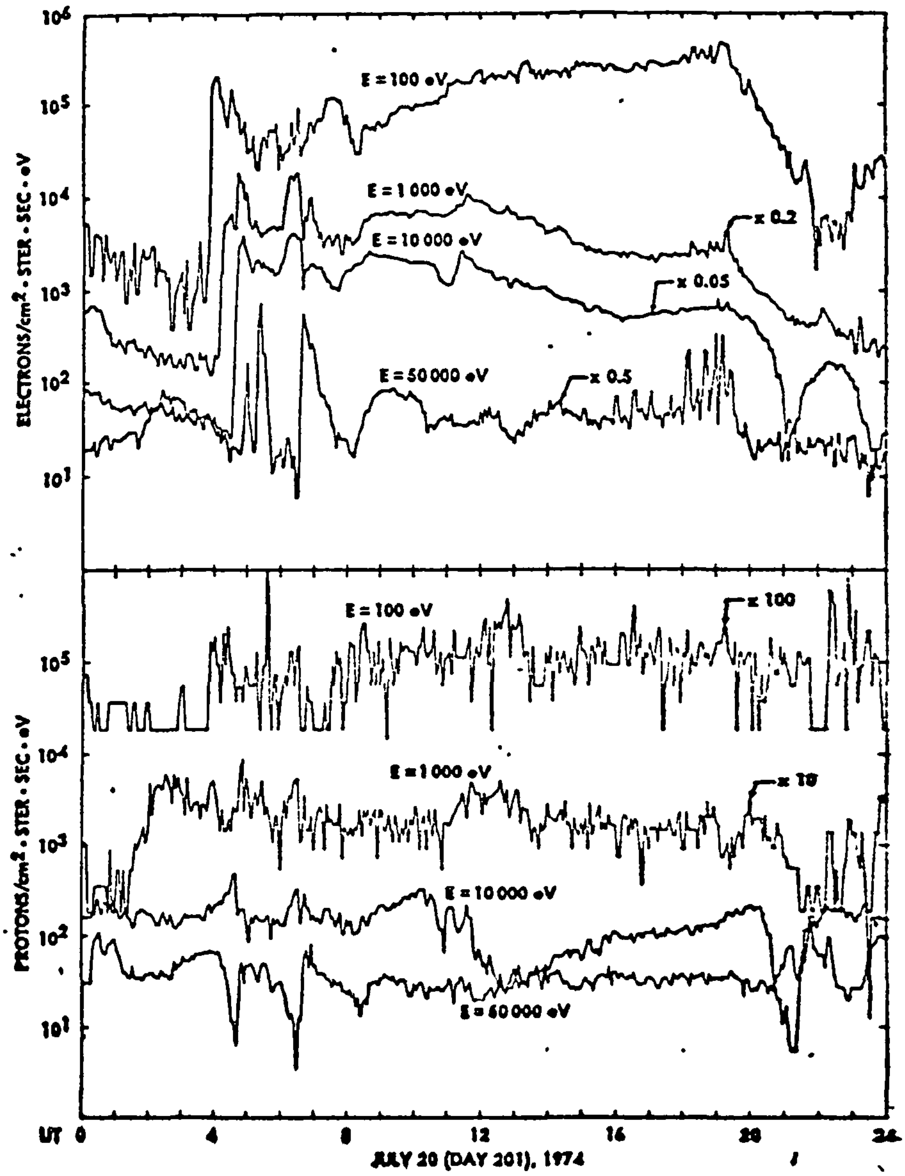
NAME
S.-Y. Su - A. Konradi



Line plots of differential number flux intensities from protons and electrons at E= 100, 1000, 10000, and 50000 ev observed by geosynchronous satellite ATS-6 located at 94° W longitude. Some of the flux intensities have been multiplied by multiplication factors indicated in the figure so as to avoid the overlay of the line plots.

Figure VII-B-10

AURORAL AND MAGNETOSPHERIC PHYSICS PROGRAM
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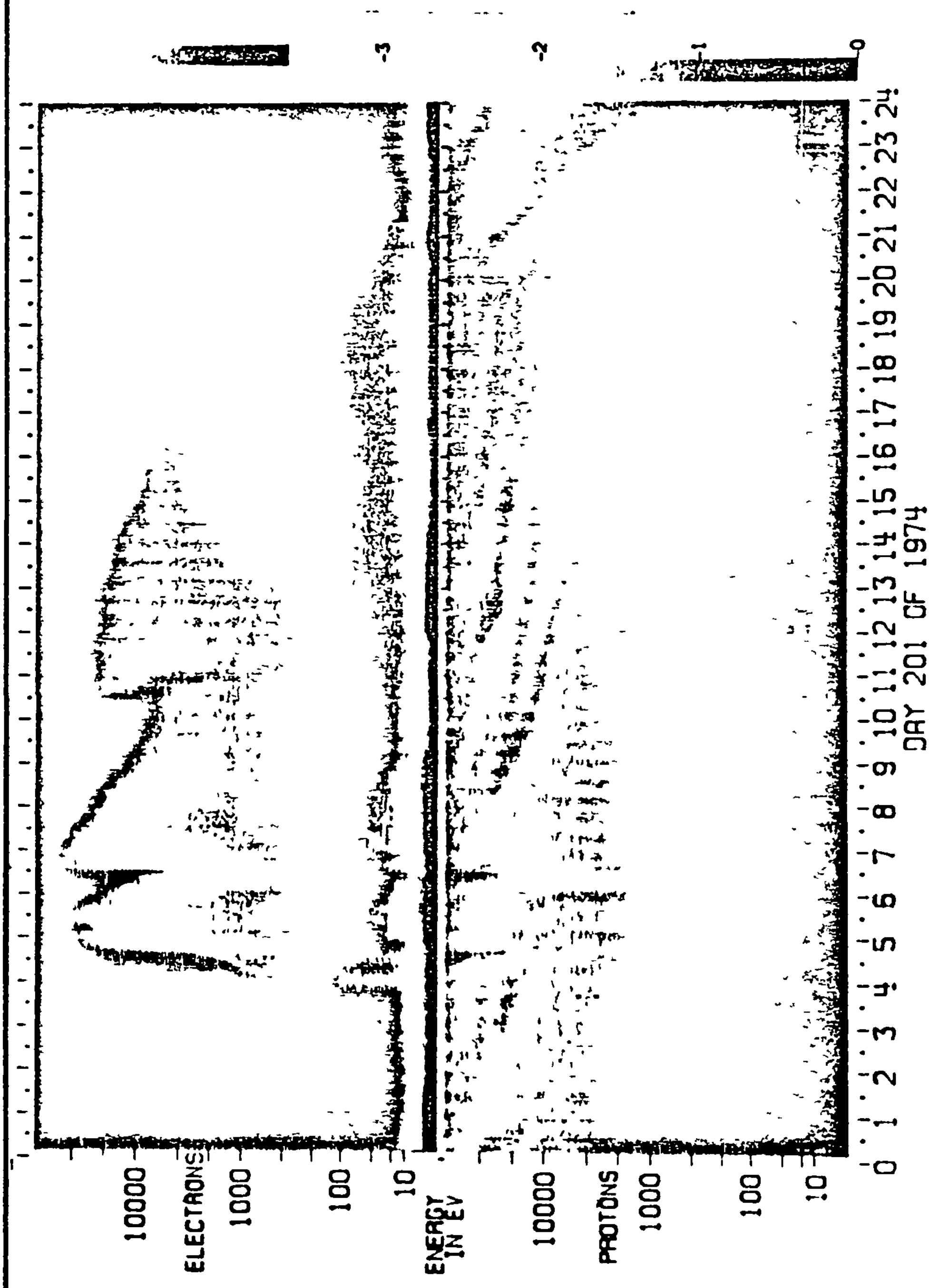


A spectrogram of the proton and electron differential energy flux during July 20, 1974. The non-linear energy scale versus universal time is used as the vertical and horizontal axis, respectively. The energy flux intensity is shown in the third dimension in gray coding. White indicates the highest and black the lowest flux intensities. For a fixed energy, the gray code from the spectrogram can be converted into a line plot of the flux intensity versus time as shown in Figure 10 (courtesy of McIlwain).

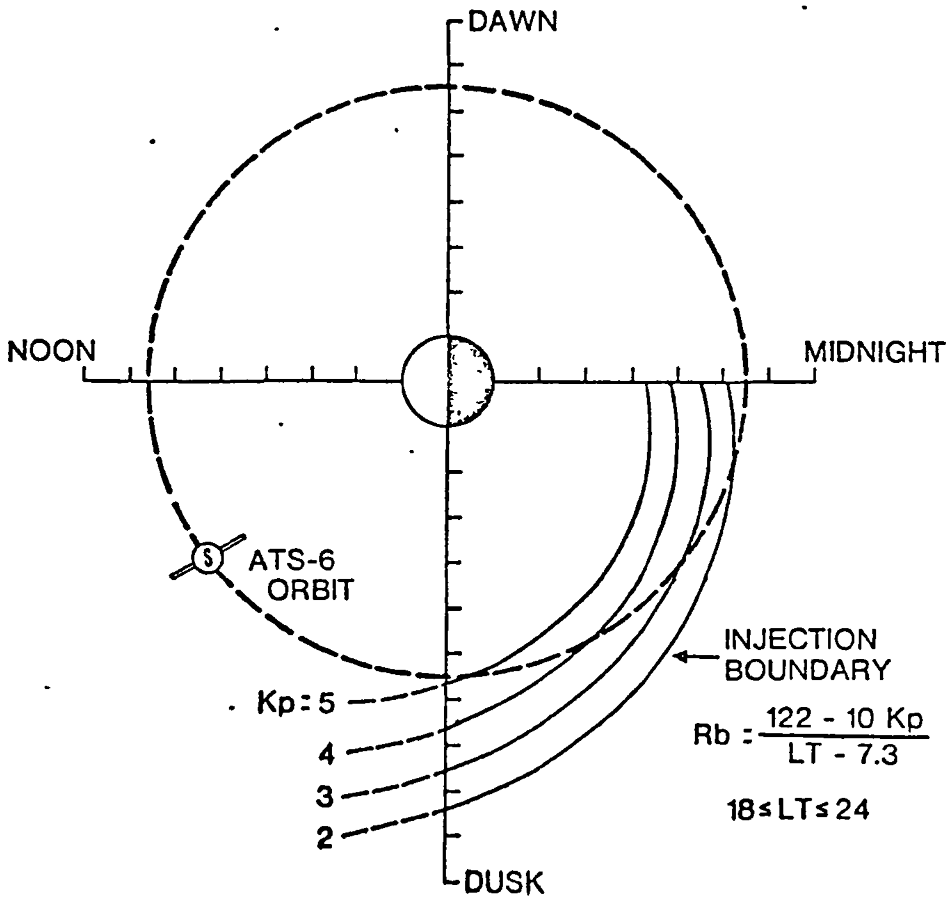
Figure VII-B-11

night-side magnetosphere. This so-called injection boundary of energized plasma cloud varies with the geomagnetic conditions as shown in figure VII-B-12. During a substorm a GEO satellite is enveloped by a high flux intensity plasma cloud in the region beyond the injection boundary in the night-side magnetosphere. The origin of the high flux intensity, energetic plasma clouds is not know. However, it is possible that they are the energized plasmas originating from the depleted plasmasphere after the plasmasphere contracts during the substorm.

Finally, a statistical summary of the particle measurement at the geosynchronous orbit is given in table VII-B-1. The result was obtained by the electrostatic analyzer onboard ATS-5 located at 105° W longitude. The particle spectrum was integrated from E = 50 to E = 50000 ev. The maximum value of flux intensity usually occurs during substorms. The protons are noted to undergo smaller changes than the electrons in fluctuation between the maximum and the minimum measured values. At most a factor of eight increase is noted for the protons between the minimum value and the maximum value. On the other hand, the electrons are seen to be highly variable in flux intensity or in number density. Increases of up to two orders of magnitude in flux intensity occur between a minimum and maximum value.

Earth Magnetic Field at Geosynchronous Altitude and its Variation with Local Time and Geomagnetic Activity: Although a geosynchronous orbiting satellite is anchored in the geographic equatorial plane it can be located off the geomagnetic equatorial plane because of the 11° tilt between the earth's rotation and magnetic dipole axes. For example, figure VII-B-13 (a) illustrates that the geosynchronous satellite ATS-1 is located very close to the geomagnetic equatorial plane since its geographic location is 150° W longitude, a place very close to the intersection of the geomagnetic and the geographic equatorial planes. On the other hand, ATS-6 is located at 94° W longitude but it is about 10° latitude north of the geomagnetic equatorial plane as seen in figure VII-B-13 (b). Because of the different geomagnetic latitudes of two satellites, the observed geomagnetic field orientations can be quite different. Figure VII-B-14 shows such observation on a geomagnetically quiet day in June. The field is measured in unit of γ (1 gamma = 10^{-5} gauss) in a spacecraft coordinate system such that the y-axis points northward along the earth spin axis, the z-axis points radially outward along the earth-spacecraft line, and the x-axis points eastward to complete the right-hand Cartesian coordinate system.

We first note that the actual observed field directions at the two geomagnetic latitudes confirm the field line orientations sketched in figure VII-B-13. However, the diurnal variations of the field magnitude in the three field components are very similar regardless of the spacecraft location at different geomagnetic latitudes. The total field strength (inferred from the dominant field component, By) is seen to be smaller in the night-side than in the dayside of the magnetosphere. The reason for this is that, as has been mentioned, the geomagnetic field lines are compressed from the solar wind bombardment on the dayside and are dragged out on the night-side. It is also evident that solar wind drag effect is noticeable at the flank of the magnetosphere from the maximum tilt of the field lines



Empirical formula for the spiral injection boundary at different geomagnetic activities. The Boundary moves closer to the earth during a geomagnetically active period so that a GEO satellite intercepts the boundary at an earlier local time in magnetosphere. A greatly enhanced particle flux intensity is observed beyond the injection boundary during a substorm.

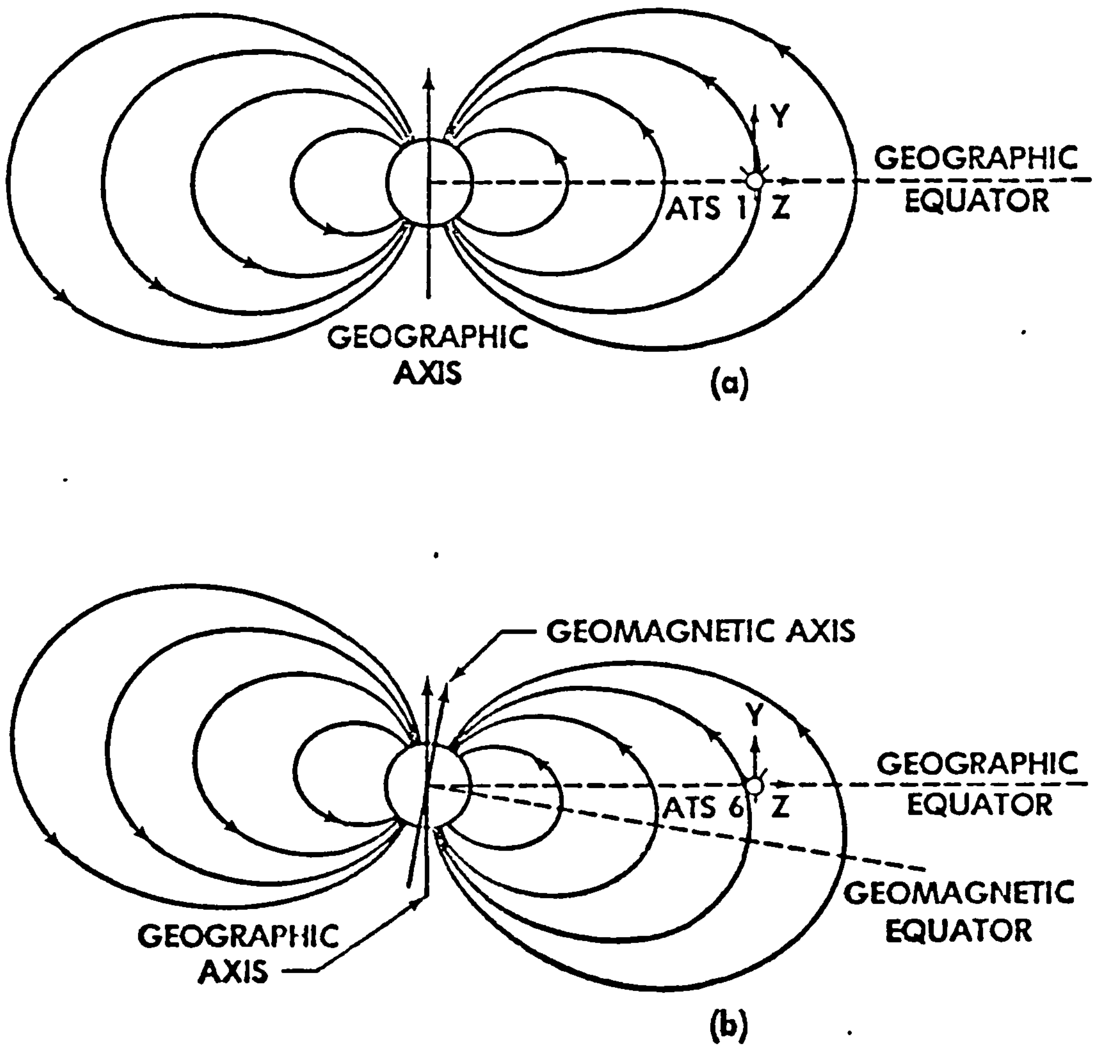
Figure VII-B-12

Table VII-B-1*

50-ev to 50,000-ev Spectral Integrals

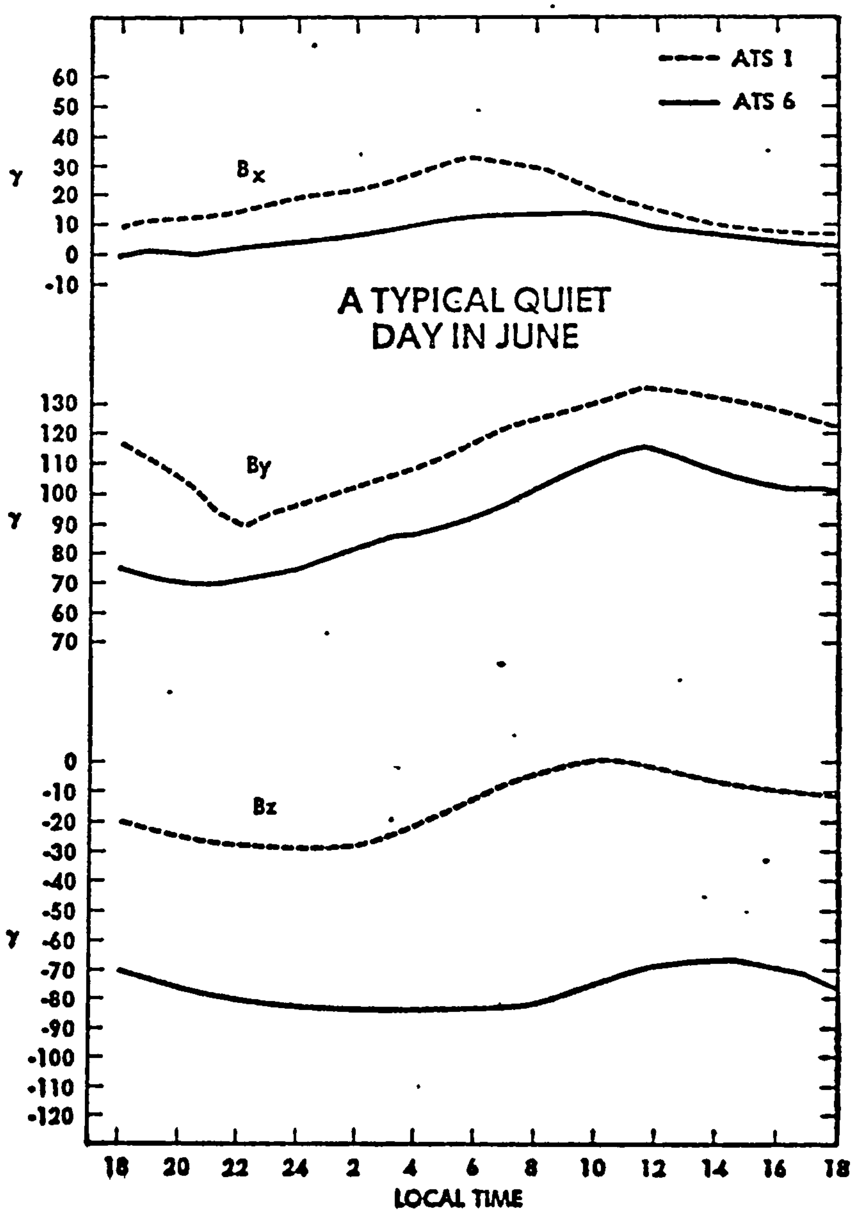
	Electrons						Protons					
	0000 LT	0300 LT	0600 LT	1200 LT	1800 LT	2100 LT	0000 LT	0300 LT	0600 LT	1200 LT	1800 LT	2100 LT
Number Density, particles/cm^3												
Minimum	0.07	0.22	0.17	0.06	0.02	0.04	0.7	0.6	0.7	0.3	0.5	0.6
Maximum	8.3	4.8	2.9	1.2	1.9	4.4	3.8	3.5	1.9	2.2	2.2	2.4
Typical	2.0	2.0	1.2	0.4	0.10	0.4	1.2	1.2	1.2	0.9	0.8	1.1
Energy Flux, erg/cm^2 sec ster												
Minimum	0.21	0.38	0.42	0.26	0.04	0.10	0.16	0.13	0.05	0.13	0.14	0.14
Maximum	9.4	15.2	14.6	2.3	1.01	7.2	0.61	0.47	0.47	0.76	0.63	0.85
Typical	3.0	3.0	1.5	1.0	0.40	0.5	0.3	0.3	0.3	0.22	0.30	0.30
Number flux, 10^6 particles/cm^2 sec ster												
Minimum	15	37	32	15	2	9	6	4	4	2	4	5
Maximum	1510	1020	832	122	162	864	25	17	16	15	23	25
Typical	300	300	200	70	30	60	12	10	8	7	8	10
Pressure, 10^{-10} dynes/cm^2												
Minimum	2.7	6	6	4	0.4	1	66	51	25	31	54	56
Maximum	190	266	173	25	14	128	235	196	169	242	255	327
Typical	50	60	30	12	7	8	140	120	90	80	90	120

*After DeForest and McIlwain, 1970



Geomagnetic field configurations in the vicinity of the geosynchronous altitudes at two different longitudes, ATS 1 location (a) versus ATS 6 location (b). The 11° tilt of the geomagnetic axis with respect to the geographic axis puts ATS 6 satellite (located at 94° W longitude) 10° above the geomagnetic equatorial plane.

Figure VII-B-13



The geomagnetic field variations at the geosynchronous orbit during a geomagnetically quiet day in June. A much larger value in the radial field magnitude seen at ATS 6 orbit indicates a larger inclination angle of the geomagnetic field line as shown in Figure 13 (b).

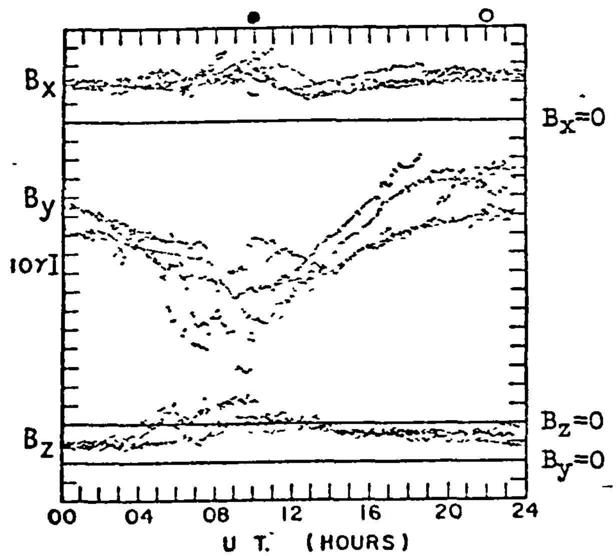
Figure VII-B-14

indicated by the deviations of the Bx component at the dawn and dusk meridians from the daily average of Bx value.

A superposition of ATS-1 magnetograms for five days with substorms is shown in figure VII-B-15. The figure shows the tendency of By component to decrease and the tendency of Bz component to increase around the local midnight (indicated by a black dot on the top of the figure) during the substorm periods. It also indicates that the Bx component tends to increase before midnight and decrease after midnight. In comparison to the quiet day field, the field during periods of substorm activity exhibits a greater vaiability at all local times and a tendency for the By component to increase on the average over the day-side hemisphere. Furthermore, during geomagnetically disturbed periods, the field in the night sector is seen to be more active before midnight than after. Of course, such active variation of field before midnight is closesly related to the fact that the particle injection boundary during a substorm is primarily located before midnight.

Unlike the particle measurement, the observed field variation at geosynchronous altitude is caused by changes in the near-by particle population as well as changes in the particle environment at a remote distance. The sequential variation of the field at different stages of a substorm activity is too complicated to determine. However, results of the montage compositions of the field configuration of the magnetosphere at quiet and disturbed geomagnetic conditions are available. Figure VII-B-16 (a) shows the noon-midnight meridian field configuration observed during a quiet time while figure VII-B-16 (b) shows the field configuration at an early stage of the substorm. Also shown in the figure are the changes in the shapes of the plasma sheet associated with the two configurations. It is seen that during a quiet period, the magnetosphere seems to be larger in size in the northsouth direction so that the field lines are less stretched to indicate a more dipole-like field configuration. Also note that the plasma sheet in the magnetotail is thicker and is located farther away from the earth in the equatorial plane (inferred result). On the other hand, at an early stage of a substorm, the magnotosphere is seen to be compressed in the northward direction. The plasma sheet becomes thinner and moves closer to the earth so that the northsouth field component near the earth is seen to decrease. Consequently, the field lines are seen to be stretched out further and become more tail-like.

Since the field line configuration affects the particle drift paths, a geosynchronous orbiting satellite is capable of observing such particle variation accompanied by the field fluctuation. Figure VII-B-17 and Figure VII-B-18 show the correlated particle and field observations made by ATS-1 and ATS-6, respectively. Both figures indicate that a decrease in the north-south field component results in a decrease in the particle flux intensity. The reason for this is that when the field configuration changes because of the decrease in the north-south field component, the spacecraft, fixed in space, starts to intercept different particle trajectories so that a different population of the particles is now being detected. In the present case the spacecraft is equivalently moving to a



A superposition of ATS 1 magnetograms for five substorm days. December 24 and 25 of 1966, and January 6, 16, and 21 of 1967. The dot and the circle indicate the local midnight and local noon, respectively, at satellite location (after Coleman and McPherron, 1969).

Figure VII-B-15

SUBJECT
Description of the Plasma Environment at Geosynchronous Altitude

NAME
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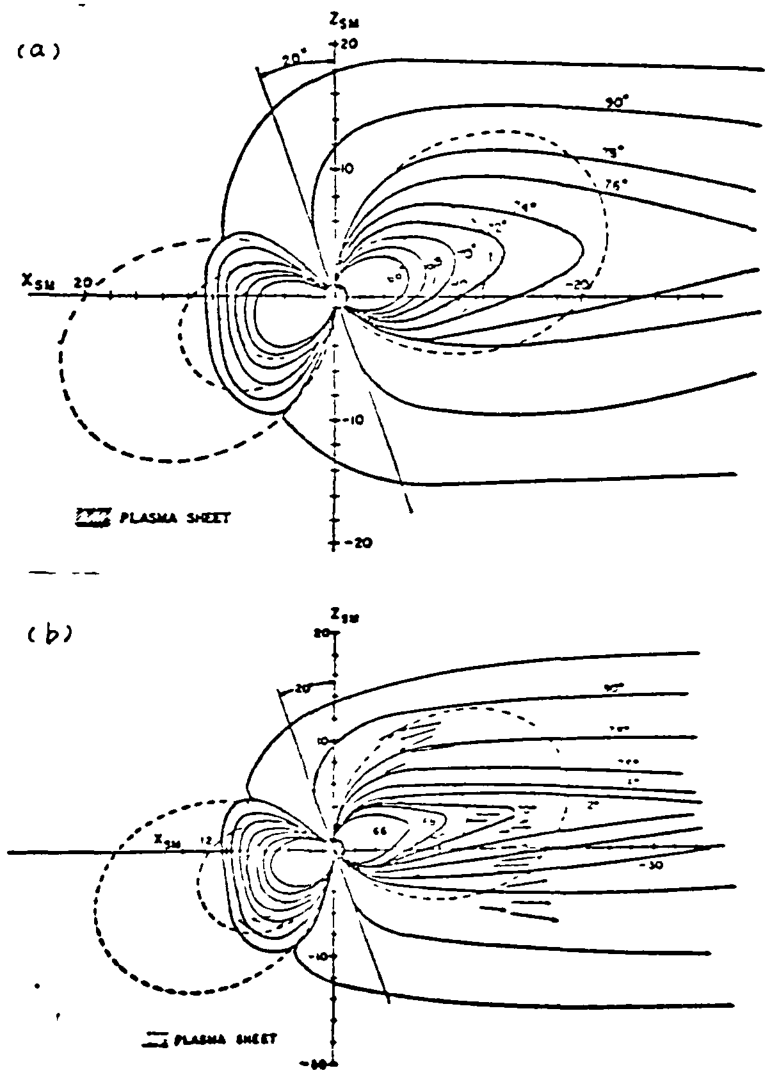
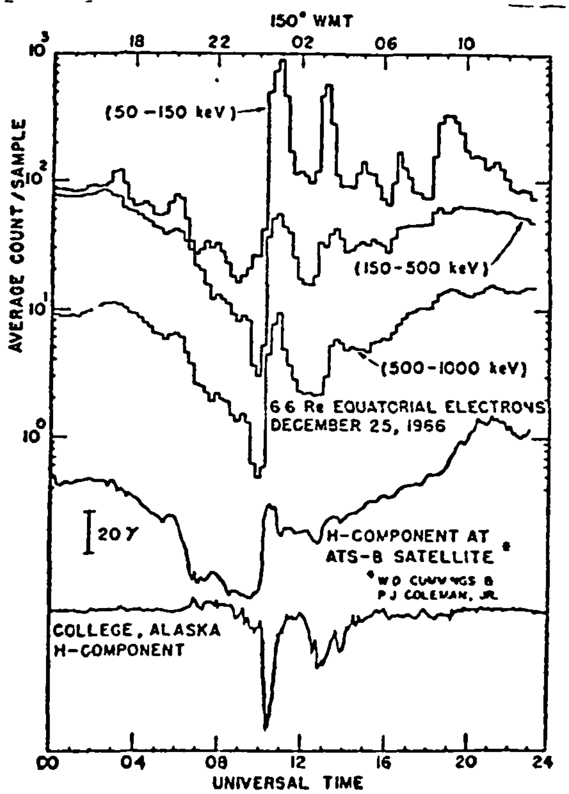


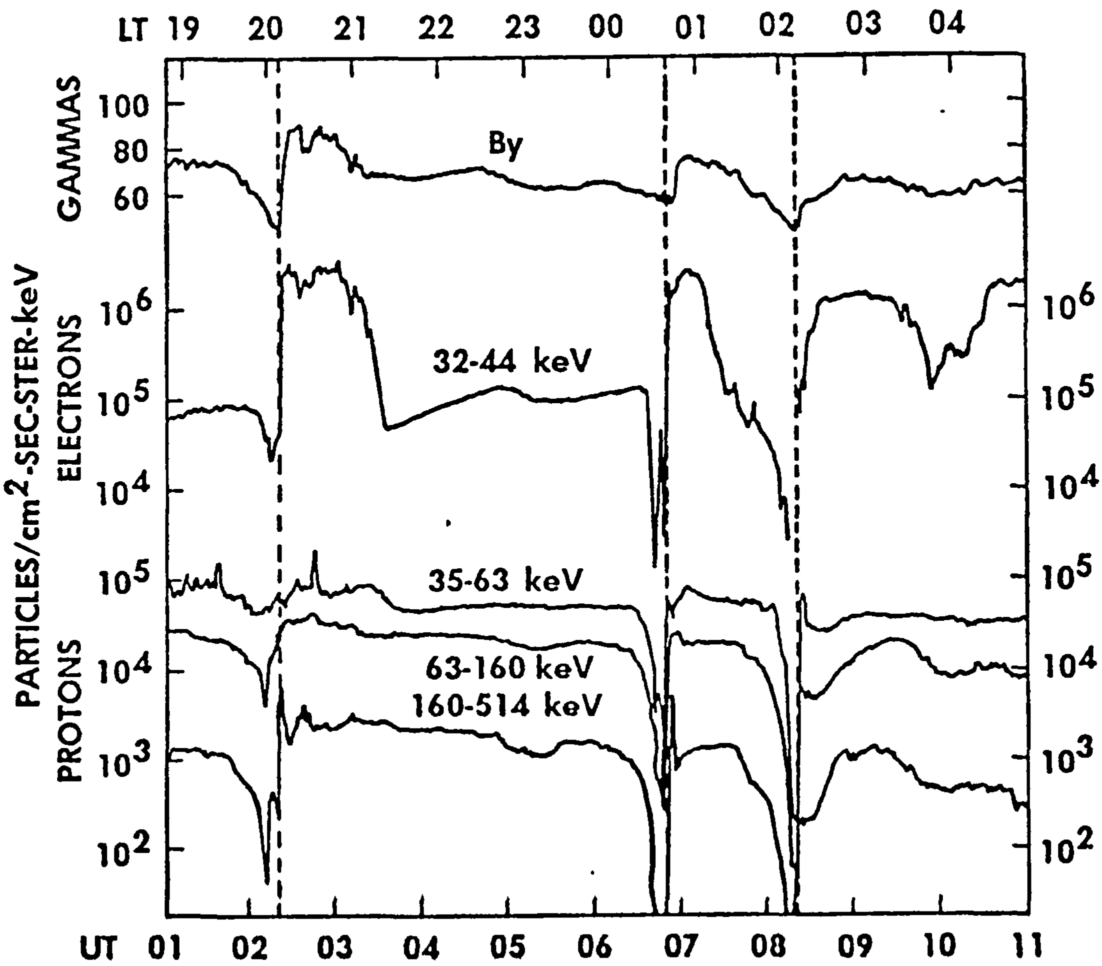
Geomagnetic field configurations in the noon-midnight meridian plane drawn to illustrate the state of the magnetosphere during a quiet post-substorm period as shown in (a) and during a substorm onset in (b). The magnetosphere is seen to be more compressed and the field lines are stretched out in the tailward direction during the early phase of a substorm The plasmasheet also becomes thinner during sub-storms. Note that the field lines near the magnetotail region relax toward the dipole field configuration after the substorm. Such changes in field line configuration can be observed at the GEO altitude (after Fairfield and Ness, 1970).

Figure VII-B-16



Variations of electron fluxes at different energy levels and the north-south component (H component) of the field strength observed by ATS-1. The horizontal north-south field component from College, Alaska magnetogram is also shown in the figure. The onset of a substorm is indicated by the sharp decrease of the H component field from the ground magnetogram. Simultaneously a sharp increase of electron flux intensity accompanied by the return (or increase) of the field strength is observed at GEO altitude (after Lezniak, Arnoldy, Parks, and Winckler, 1968).

Figure VII-B-17



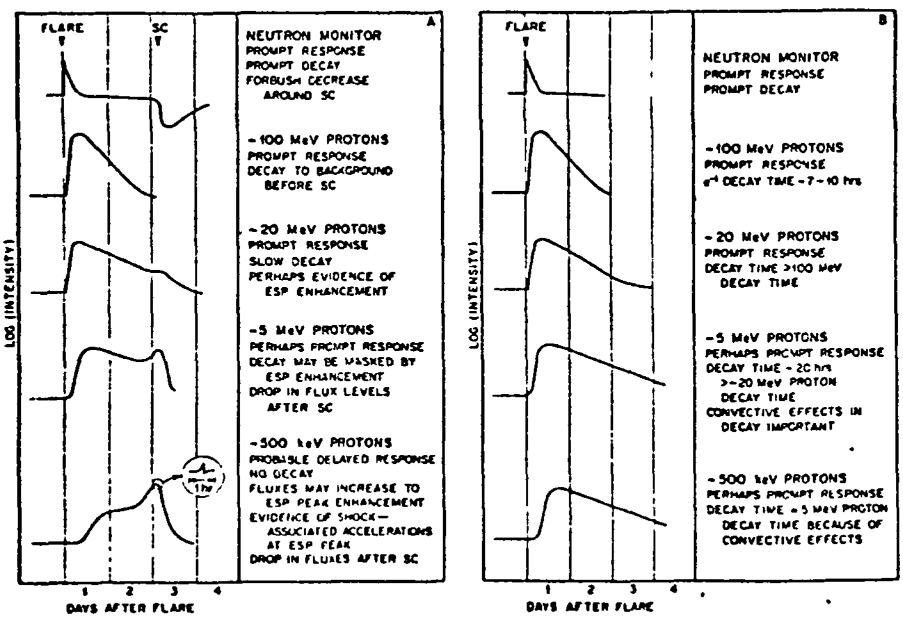
Similar example as in Figure 17 to show the correlation between the proton and electron flux increases and the field strength increase observed by ATS-6 satellite during three substorms which occurred on August 5, 1974 (after Walker, Erickson, Swanson, and Winckler).

Figure VII-B-18

large L value so that lesser flux intensity is observed (c.f., figures VII-B-2 and VII-B-3).

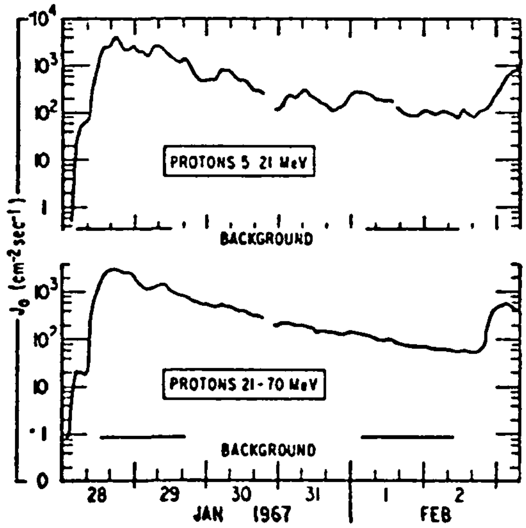
During the field recovery, the particle fluxes are also seen to recover their intensities. Sometimes even higher flux levels are detected because of encounters with newly injected plasma occurring following substorms. Such one to one correspondence between the field and particle variations are very common in the dark magnetosphere during a substorm period.

Appearance of High Energy Proton Fluxes during Solar Flare Associated Events: During the solar flare event, the sun emits an unusually large dose of high energy electrons and protons. The propagation of the high energy particles has been well investigated by solar high energy particle physists and the results can be found in the literature (see for example the review article by L. J. Lanzerotti, 1974). Here we will only recapitulate the result of the observation of the solar proton fluxes propagatin in interplanetary space. Figure VII-B-19 shows a schematic illustration of the proton flux observation at the earth after a solar flare event. Part A of the figure indicates the modification of the lower energy protons when the flare produced interplanetary shock wave is propagating toward the earth, while part B shows the result without the shock wave. The satellite observations of the actual solar proton fluxes at geosynchronous altitude are shown in figure VII-B-20 where no shock wave is observed and accompanied by the interplanetary shock wave, in figure VII-B-21.



Idealized, schematic illustration of the solar proton fluxes at various energy levels measured near the earth orbit following a flare eruption in the sun's western hemisphere, (a) The flare-produced shock is also observed at the earth and (b) no shock is observed at the earth (after L. J. Lanzerotti).

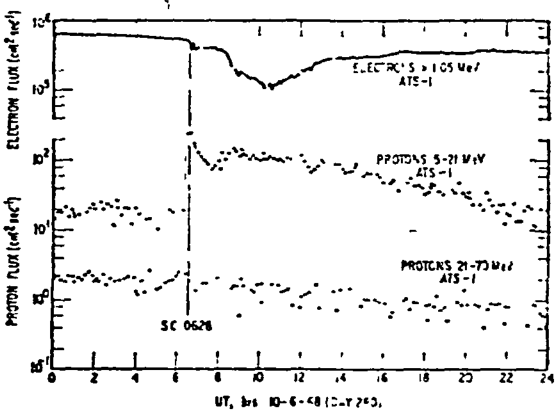
Figure VII-B-19



The solar proton observations at the GEO orbit after 28 January 1967 flare event. No shock accompanied the flare in this event (after Blake, Paulikas, and Freden).

Figure VII-B-20

AURORAL AND MAGNETOSPHERIC PHYSICS PROGRAM NASA-Lyndon B. Johnson Space Center	DATE	NOTE NO	PAGE
SUBJECT Description of the Plasma Environment at Geosynchronous Altitude	NAME S.-Y. Su - A Konradi		



The solar proton observation at the GEO orbit on October 6, 1968. The >1.05 Mev radiation trapped electron flux is also plotted for reference. The large enhancement of the 5 - 21 Mev energetic solar protons are associated with the arrival of the interplanetary shock wave produced by the flare (after Paulikas and Blake).

Figure VII-B-21

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VII. ENVIRONMENTAL FACTORS

B. IN-SPACE OPERATIONS

1. RADIATION

VII-B-1-b Biological Considerations to Establish Shielding Criteria

A. C. Hardy
Mission Planning & Analysis Div

The radiation environment to be encountered by the Satellite Power System (SPS) varies with the different SPS phases. In low earth orbit and transit to synchronous altitude the primary radiation concern is related to the protons and electrons trapped in the earth's magnetic field (Van-Allen belts). At synchronous altitude, SPS will be exposed to the outer radiation belt electrons, galactic cosmic rays, and solar radiation (solar particle events).

The major impact to SPS from radiation is on EVA activities at both synchronous and low earth orbital altitudes.

The current NASA biological radiation exposure limits are shown in table VII-B-2

Low Earth Orbit (LEO) SPS Construction

Radiation exposure in low earth orbit is dependent upon the orbital altitude and inclination, the vehicle shielding, and the mission length. Table VII-B-3 gives on-orbit stay times for different altitudes with 2.0 and 5.0 gm/cm^2 of aluminum shielding. EVA in conventional space suits (Apollo and Skylab type) can reduce the table VII-B-3 stay times considerably. SPS LEO construction with continuous EVA (three 8-hour shifts) will result in a reduction of the 5 gm-30^o stay times by about a factor of ten, i.e., 300 n.m stay time to 21 days, 400 to 10 days, and 500 to 4 days. This reduction assumes that dosage is evenly distributed among the three EVA shifts. Figure VII-B-22 shows the location of the South Atlantic anomaly (SAA) and also how the dose is received with time at an altitude of 240 nm. The anomaly increases in size and radiation intensity with increasing altitude resulting in an increasing duration and magnitude of the dose pulses received during SAA passes. Clearly, most of the dose is received during successive passes through the SAA. Conventional EVA suits can be utilized for LEO SPS construction with only minor reduction in the stay times listed in table VII-B-3 if EVA activities are restricted to the 15 to 18 hour low dose periods between the SAA pass groups (figure VII-B-22).

Transit to Synchronous Altitude

The dose received during transit to synchronous altitude is dependent to some extent upon the shielding, but mostly upon the time spent in the radiation belts. For fast transit similar to Apollo, doses will be low (< 5.0 rem skin). For continuous acceleration slow transit, the dose to exposed equipment such as solar cells will be fairly high. Dose vs thickness for slow transit is shown in figure VII-B-23. The slow transit mode should not be considered for crew transport.

Geosynchronous Earth Orbit (GEO)

For the basic description of the GEO radiation sources and their effects, reference the attached Rockwell report.

The geosynchronous radiation environment impact to SPS from knowledge currently available is summarized as follows.

Galactic Cosmis Rays - Cosmic rays will give continuous low level exposure (25 to 36 mr/day). This exposure is relatively uneffected by shielding because of the high energies involved. Depending upon the outcome of the current controversy relative to the biological effect of high HZ particles, cosmic rays can be a significant factor for crew career exposure limitations.

Outer Belt Electrons - Until a better understanding of the short term electron intensity variations with magnetic storm activity is achieved, all firm conclusions must be derived from the existing time averaged environment models. Since SPS represents the first serious consideration for manned synchronous activities, it poses the first real requirement for GEO short term environment modeling.

GEO Crew Quarters Shielding - Since crew quarters shielding at synchronous altitude is a long term concern, use of the time averaged electron environment model is justified. Figure VII-B-24 shows the AE-4 electron model dose versus thickness at synchronous altitude. Since the primary electron dose increases very rapidly with decreasing thickness, the shielding objective should be to eliminate the primary dose component from within the crew quarters. Between 2 and 3 gm/cm^2 of equivalent aluminum shielding is sufficient to eliminate the primary electrons and result in an average Blood Forming Organ exposure of $\sim$ 0.2 rem/day. This gives 175 day mission stay time excluding exposure from EVA and solar particle events.

GEO EVA Shielding - SPS construction at synchronous altitude cannot be accomplished with unrestricted EVA in conventional space suits similar to those used during Apollo and Skylab. The time averaged electron model gives EVA shielding requirements of between 1.5 and 2.0 gm/cm^2 of equivalent aluminum material. The objective is to select the optimum thickness which allows the skin and depth exposure limits to be approached at the same relative rate. For SPS GEO operations where EVA time selection may be less critical, it may be possible to utilize conventional suits. Even though the short term electron variations are not understood in detail, we do know a little about what goes on. Diurnal intensity changes are about a factor of 10 with minimum near local mignight. Magnetic storm activity causes changes in electron intensities of about a factor of 100 with increases that may persist for several days. Orbital positions and inclination can also influence the radiation exposure. (See Rockwell report) Soft suit EVA at synchronous altitude will be possible if the minimal exposure conditions can be utilized. The degree of conventional suit EVA restrictions can only be determined with detailed assessment of the short term environment conditions.

Solar Particle Events at Synchronous Altitude - The degree of protection of the SPS crew from solar particle events is dependent upon the spacecraft shielding. There are two approaches for determing the shielding requirements. One is to assume long on-orbit stay times and evaluate the exposure conditions from multiple events. The other is to evaluate the exposure conditions related to a single large event. In either case, any conclusion and/or recommendations must come from studies of past solar particle event histories. The single large event approach seems to be best for the following reasons: (a) Large events do not usually occur during the same immediate timeframe. (figure VII-B- 28 of Rockwell report) (b) Protection from a large event automatically provides protection from several small ones. (c) Excessive exposure can be received from a single large event. (The August 1972 event produced almost as much radiation as the total of all other events thus far in the 20th Solar Cycle.) Table VII-B-1-IV shows a type of protection factor table for events that have occurred during the past 20 years. The allowable exposure as a percentage assumes that some portion of the dose limit must be allocated for GEO electron and cosmic ray exposure. Protection of 100% (as shown in the table) will require very heavy shielding ($\sim$ 30 gm/cm^2) which may be impractical or impossible to attain for SPS.

The final SPS solar particle event shielding requirements must be determined from trade-off studies which consider such parameters as exposure constraints, vehicle design, weight limitations, risk vs gain rationale, etc.

Table VII-B-2

Suggested Exposure Limits and Exposure Accumulation Rate Constraints for Unit Reference Risk Conditions

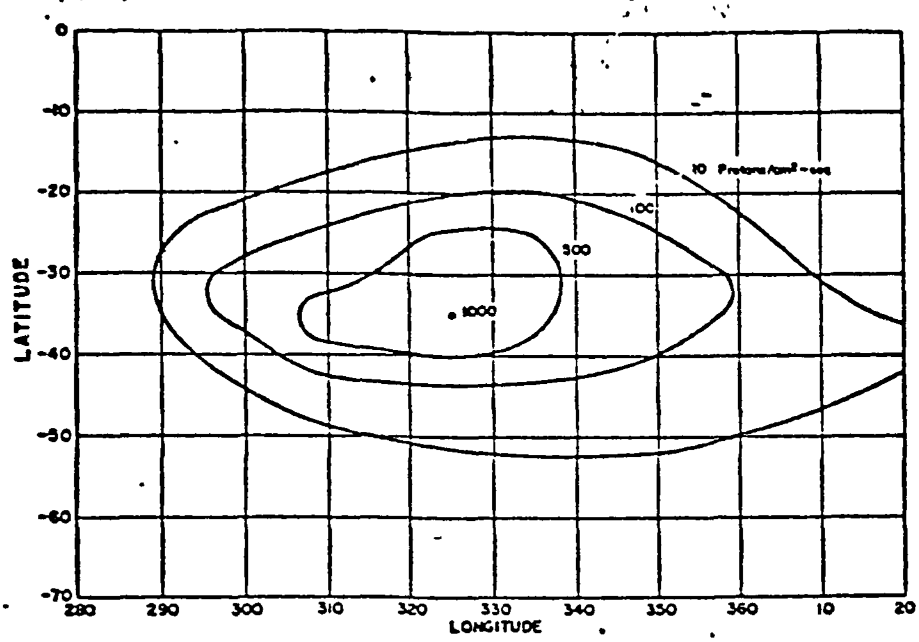
Constraint	Primary Reference Risk (rem at 5 cm)	Ancillary Reference Risks: Bone Marrow (rem at 5 cm)	Skin (rem at 0.1 mm)	Ocular Lens (rem at 3 mm)	Testes (rem at 3 cm)
1-year average daily rate		0.2	0.6	0.3	0.1
30-day maximum		25	75	37	13
Quarterly maximum[a]		35	105	52	18
Yearly maximum		75	225	112	38
Career limit	400	400	1200	600	200

[a] May be allowed for two consecutive quarters followed by 6 months of restriction from further exposure to maintain yearly limit.

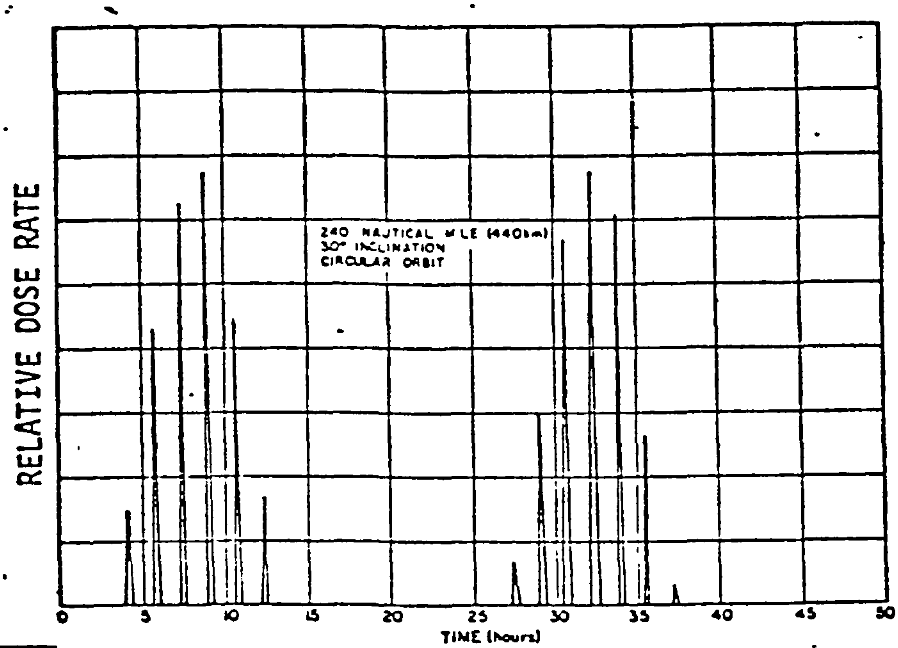
Table VII-B-3

MISSION LENGTH TO EXCEED QUARTERLY EYE DOSE LIMIT
(52 REM) WITH 2.0 AND 5.0 GM/CM^2 SHIELDING FOR 0^o AND 30^o INCLINATION ORBITS

ALTITUDE (N.MI.)	MISSION LENGTH (DAYS)			
	2.0 GM/CM^2		5.0 GM/CM^2	
	0^o INC.	30^o INC.	0^o INC.	30^o INC.
200	>600	140	>600	520
300	420	70	>600	200
400	140	28	500	100
500	56	14	104	50



PROTON ISOFLUX PLOT - 240 NAUTICAL MILE ALT.
(SOUTH ATLANTIC ANOMALY)



RELATIVE PROTON DOSE RATE WITH TIME FOR
30-DEGREE, 240 NAUTICAL MILE ORBIT

Figure VII-B-22

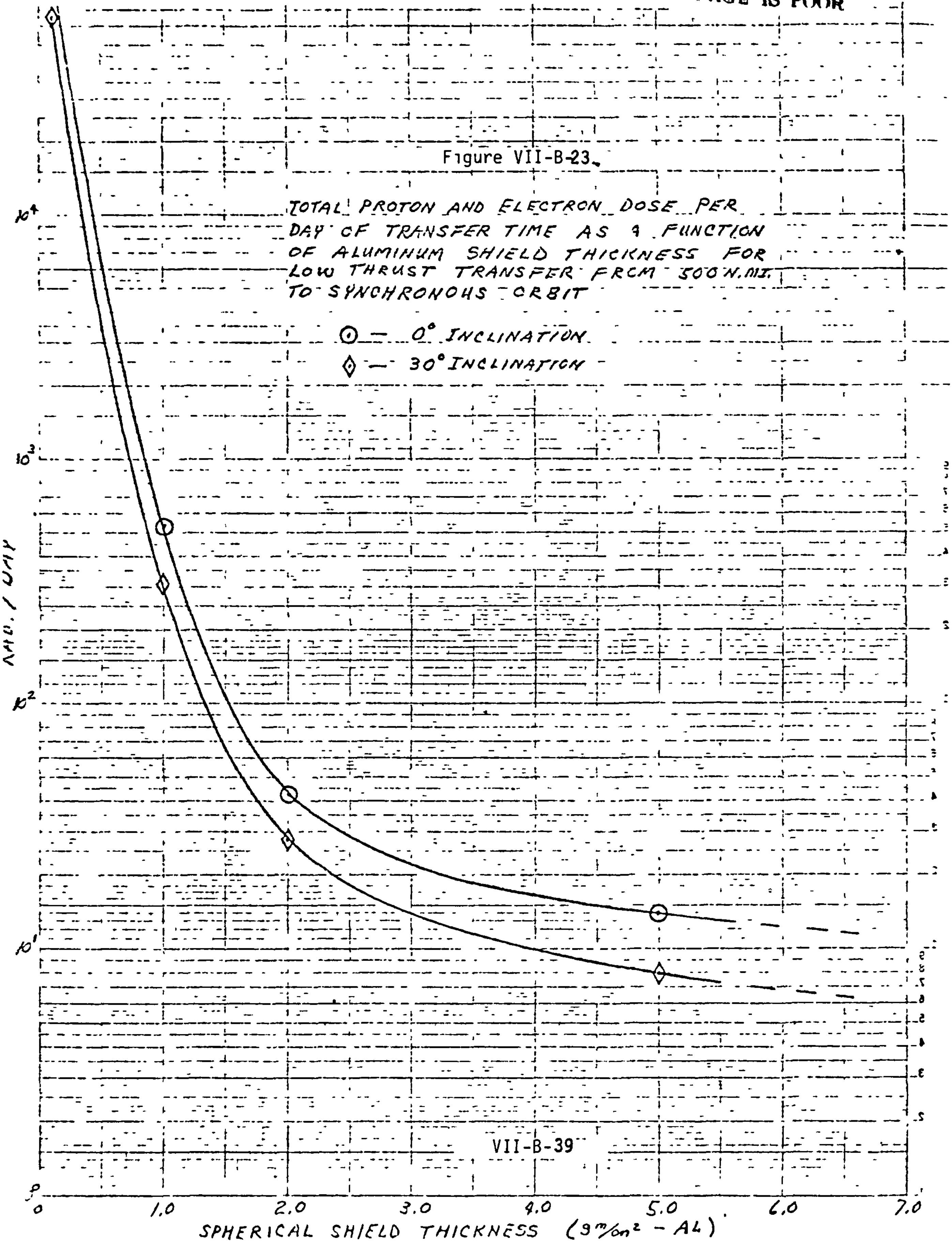


Figure VII-B-23.

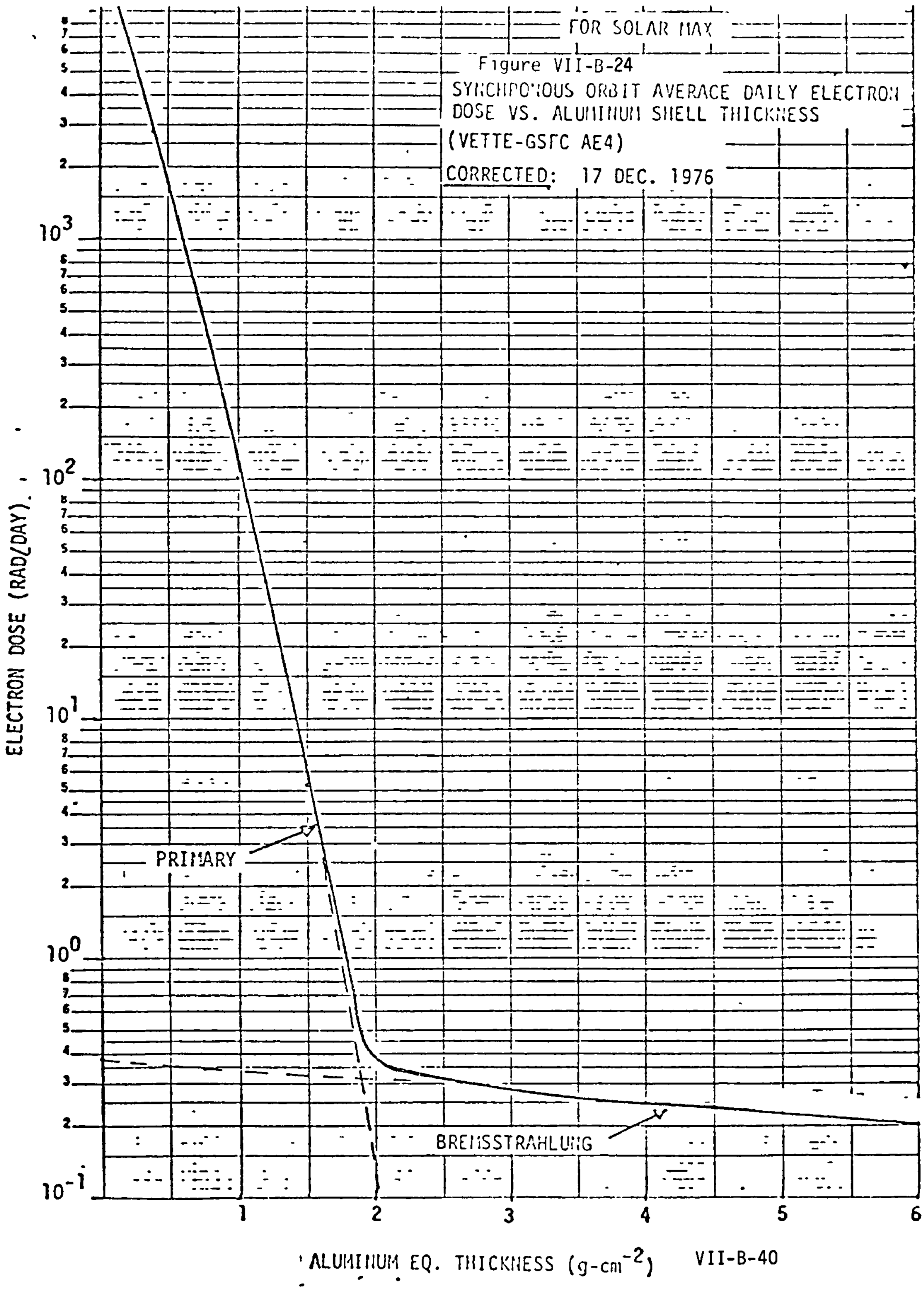

FOR SOLAR MAX
Figure VII-B-24
SYNCHRONOUS ORBIT AVERAGE DAILY ELECTRON DOSE VS. ALUMINUM SHELL THICKNESS
(VETTE-GSFC AE4)
CORRECTED: 17 DEC. 1976
ELECTRON DOSE (RAD/DAY)
10^3
10^2
10^1
10^0
10^-1
PRIMARY
BREMSSTRAHLUNG
1
2
3
4
5
6
ALUMINUM EQ. THICKNESS (g-cm^-2)

Table VII-B-4

SOLAR PARTICLE EVENTS AT SYNCHRONOUS ALTITUDE

SHIELDING EFFECT FOR SOLAR CYCLES 19 AND 20 EVENTS
(54 EVENTS 1956 - DATE WITH FLUX MORE THAN $10^6 P/CM^2$ >30 MEV.)

PERCENTAGE OF EVENTS WITH DOSAGE LESS THAN THE ALLOWABLE EXPOSURE				
SHIELDING (gm/cm^2 OF AL)	ALLOWABLE EXPOSURE - % OF BFO QUARTERLY LIMIT (35 REM)			
	10	30	50	100
2.0	69	83	85	93
10.0	80	89	94	98
30.0	98	100	100	100

Space Division
Houston Office, Field Operations
1840 NASA Boulevard
Houston, Texas 77058

Rockwell
International

January 18, 1977

TO: A. C. Hardy, FM2

SUBJECT: SPS Radiation Environment

The enclosed documentation is a brief report of work performed on the SPS radiation environment at geosynchronous altitude during the period 1 October through 31 December 1976.

E. R. Beever
Project Engineer
Shuttle Radiation Analysis
Flight Operations, Houston

ERB/ag

cc: R. G. Rose, FA
R. K. Swim, D/101

SOLAR POWER SYSTEMS

GEOSYNCHRONOUS RADIATION ENVIRONMENT

31 DECEMBER 1976

ROCKWELL INTERNATIONAL
SPACE DIVISION
HOUSTON OPERATIONS
SHUTTLE RADIATION ANALYSIS

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SOLAR POWER SYSTEMS GEOSYNCHRONOUS RADIATION ENVIRONMENT

INTRODUCTION

The natural space radiation environment at geosynchronous altitude consists of the galactic cosmic rays, geomagnetically trapped particles, and occasional bursts of energetic particles from the sun (solar particle events). The environment is a severe one for manned operations, and shielding assessments are complicated by the temporal variations in the environment and the requirement to account for non-forecastable exposures due to increases in the trapped environment and the occurrence of solar particle events.

The earliest shielding calculations of synchronous orbit radiation were performed by Burrell, et al (1) using the AE-3 model electron environment (2). The latest work in the area is by Wilson and Denn (3) who have scaled Burrell's data upward to place it in better agreement with the higher energies of the current AE-4 electron model (4). These studies and other data from the literature have been used where applicable. All of the AE-4 calculations included here and the 20th cycle solar proton event doses were calculated as part of this study.

The following sections review the synchronous radiation sources and their shielding implications for manned operations.

GALACTIC COSMIC RAYS

Galactic cosmic rays are composed of 87% protons, 12% alpha particles and 1% heavier nuclei. Because of the secondary radiations produced in attenuating these very high energy particles, protecting against them is impractical. Figure VII-B-25 indicates that the dose rate remains relatively constant for shield thicknesses up to about 50 g/cm^2. Fortunately, the galactic cosmic rays are not an intense source and, therefore, will produce a continuous low level exposure to the SPS crew and equipment.

The lower energies of the GCR vary with the solar cycle. From Apollo experience (5), the geosynchronous exposure rates will range from approximately 24 mrad/day at solar maximum to about 36 mrad/day at solar minimum.

Since there are unresolved questions about the interactions of high energy heavy particles with tissue (7), long term exposure to galactic cosmic rays may be a significant factor in career dose limitations.

GEOMAGNETICALLY TRAPPED RADIATION

The trapped radiation at synchronous altitude consists of both protons and electrons. The protons are low in energy and of small concern while the electrons have energies extending to several MeV and are quite penetrating. A dose versus thickness curve using the current electron model of the outer zone electrons, AE-4 (5), is shown in Figure VII-B-1-26. The current model does not account for changes due to the solar cycle at geosynchronous altitude although it is probable that higher electron fluxes are present during conditions of solar minimum (8).

A new outer zone electron model, AE-7, is expected to be released soon (9). Although there are some unresolved problems with the higher energies of the new model, it is understood that it will be similar to AE-4 up to 2.0 or 2.5 MeV.

From Figure VII-B-26 , it is apparent that aluminum shielding of 2.0 to 2.5 g/cm^2 will limit the crew radiation exposure to that received from the secondary x-rays (Bremsstrahlung) produced in the habitat walls.

Local Time Variations

ATS-1 measurements (10) showed that the electrons at geosynchronous altitude undergo significant diurnal changes in intensity, varying from a maximum about an hour before local noon to a minimum about an hour before local midnight. Figure VII-B-27 shows how the differential spectrum changes during the day. Dose versus thickness curves for local times of 0400, 0800, 1100, and 2300 hours are shown in Figure VII-B-28. There is more than a factor of 10 difference at 1.5 g/cm^2 between local noon and local midnight. It may be necessary to forego EVA operations near local noon.

The diurnal variations are sometimes masked by large increases due to geomagnetic storms which are described next.

Geomagnetic Storms

A severe and long-lasting magnetic disturbance that occurs worldwide is called a magnetic storm which is often accompanied by auroral displays and ionospheric disturbances which disrupt radio communications.

Geomagnetic storms produce variations in the intensity of trapped electrons which are quite pronounced at the geosynchronous orbit. During intense storms electron intensities have been observed to increase by more than two orders of magnitude and to persist for a week or so. The intensities rise rapidly to a peak value and decay slowly. In Figure VII-B-29 the Kp index is a ground-based measurement of geomagnetic activity. The higher the Kp index, the more intense the storm.

The AE-4 electron model is time averaged so that long duration missions, and stay periods within a habitat which excludes primary electrons, are adequately accounted for. The model, however, does not account for the peak enhancement of the storms which could be important to lightly shielded cases such as EVA.

Longitude Effects of Equatorial Orbits

Because the earth's magnetic poles are offset from the earth's axis, the magnetic equator coincides with the geographical equator only at longitudes of about 10^{o}W and 150^{o}W. At synchronous altitude there is a drop-off of radiation with increasing magnetic latitude. ATS-6 measurements (8) at a magnetic latitude of 10^{o} were about a factor two lower than ATS-1 measurements at the magnetic equator. Figure VII-B-30 illustrates the offset of the two equators at 70^{o}W longitude.

SOLAR PROTON EVENTS

The emission of high energy protons from the sun pose a hazard to man in space due to the damaging effects caused by the penetrating radiation. The problem is compounded by the fact that the time of occurrence, spectral shape, and intensity cannot be accurately forecasted. It was earlier thought that the earth's magnetic field and magnetosphere would impede or attenuate most of the incoming solar particles. For low altitude and small inclination, this is true. However, data from ATS-1 and other synchronous-orbiting satellites indicated that solar protons, for the most part, have direct access to the synchronous altitude region (10,11).

Figure VII-B-31 shows the solar proton events that have occurred over the past two solar cycles (12). Burrell, et al, (1) have estimated the solar proton event (SPE) skin and blood-forming organs (BFO) doses for the 19th solar cycle as shown in Table VII-B-5. We have computed the SPE skin and BFO doses for the 20th solar cycle. These are shown in Table VII-B-6. In Figure VII-B-32 we have plotted the normalized dose (dose/proton with energy$\geq$30 MeV) vs. shield thickness for several event characteristic rigidities, Po. Po is a measure of the spectral hardness. If one knows the total number of protons greater than 30 MeV/cm^2, and the associated characteristic rigidity, then the dose for a given thickness can easily be determined from this figure.

As mentioned above, solar proton event characteristics (spectral shape, event size, etc.) cannot be accurately predicted. More recent investigators (12, 13, 14) have determined probabilistic fluxes and doses as a function of mission duration and confidence level. In Figure VII-B-33 Burrell's (13) data has been reproduced depicting the monthly probability of obtaining a solar proton event of a given event size. These data were used in Table VII-B-7 to generate the percentage of 19th and 20th cycle

solar proton events which did not exceed various levels of allowable quarterly BFO dose. These data were computed based on 54 events with event size greater than 10^6 protons/cm^2 with $E \geq 30$ MeV.

This seems to indicate that a shield of 10 gm/cm^2 will protect the crew against expected solar particle events.

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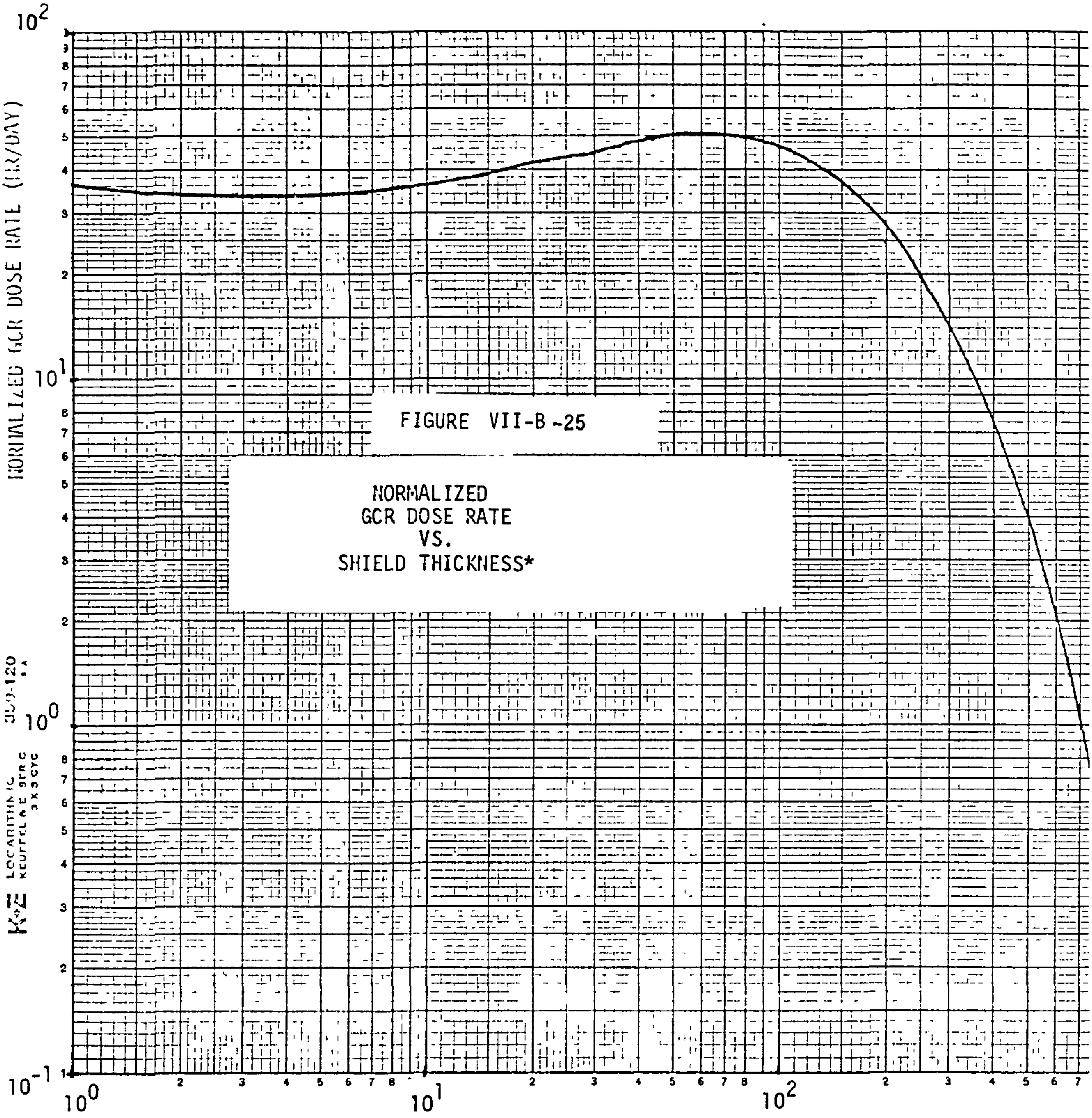


FIGURE VII-B-25

NORMALIZED
GCR DOSE RATE
VS.
SHIELD THICKNESS*

ALUMINUM SHIELD THICKNESS (GM/CM^2)

*FROM HAFFNER - NORMALIZED TO APOLLO RESULTS

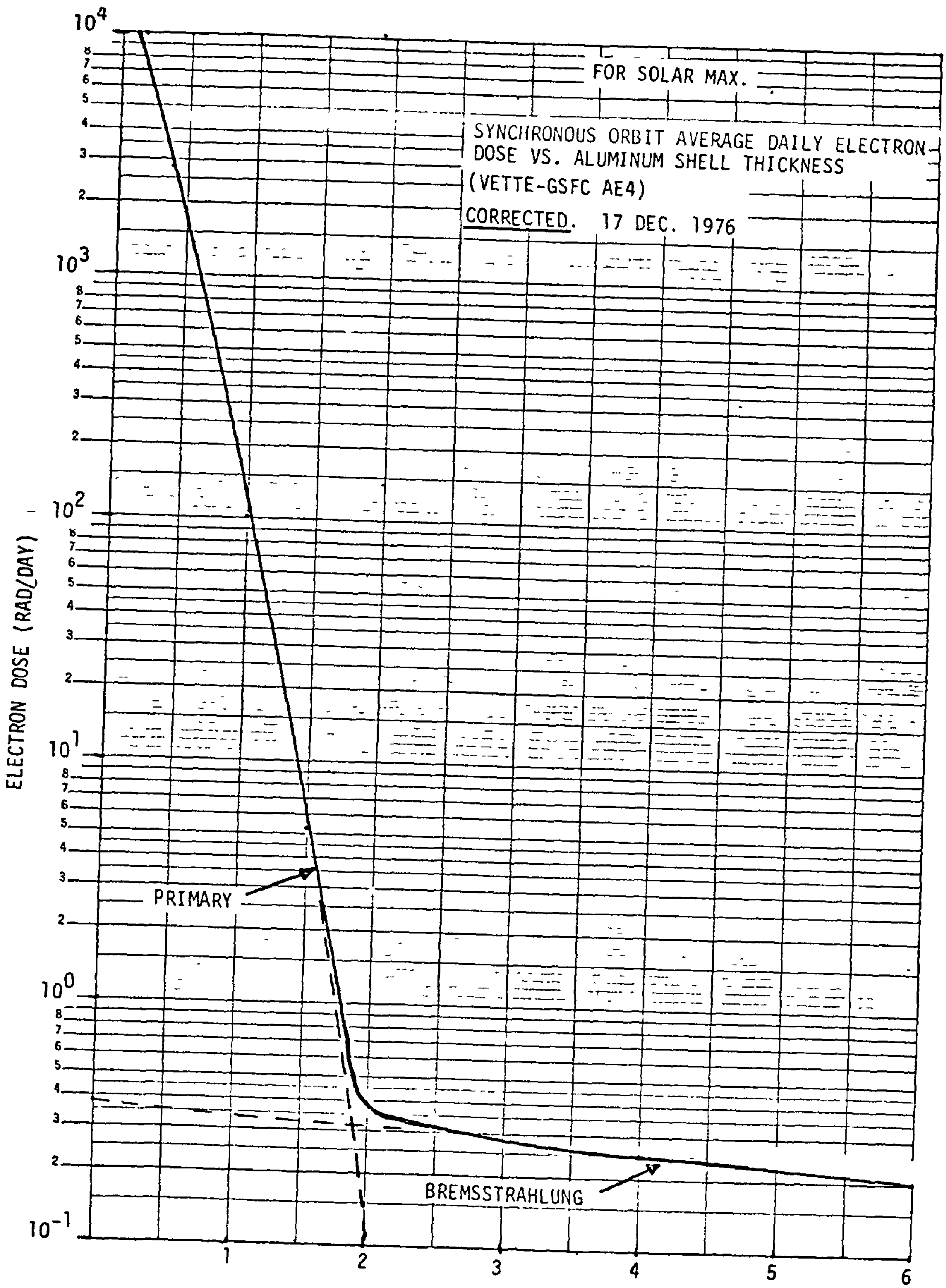


Figure VII-B-26. ALUMINUM EQ. THICKNESS ($g\text{-}cm^{-2}$)

FIGURE VII-B-I-27 DIFFERENTIAL ELECTRON FLUX
VS.
LOCAL TIME
FOR VARIOUS ENERGIES

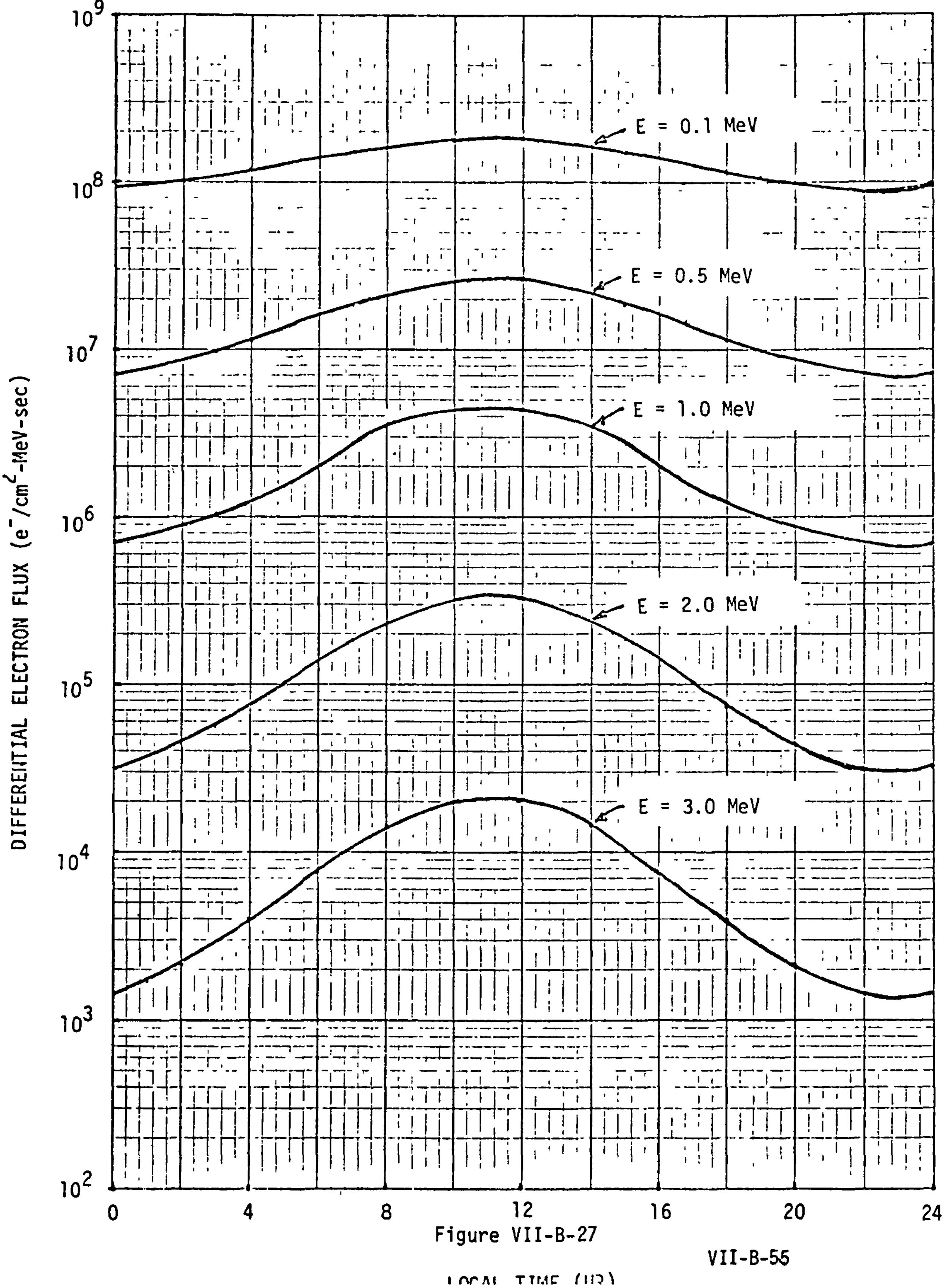


Figure VII-B-27

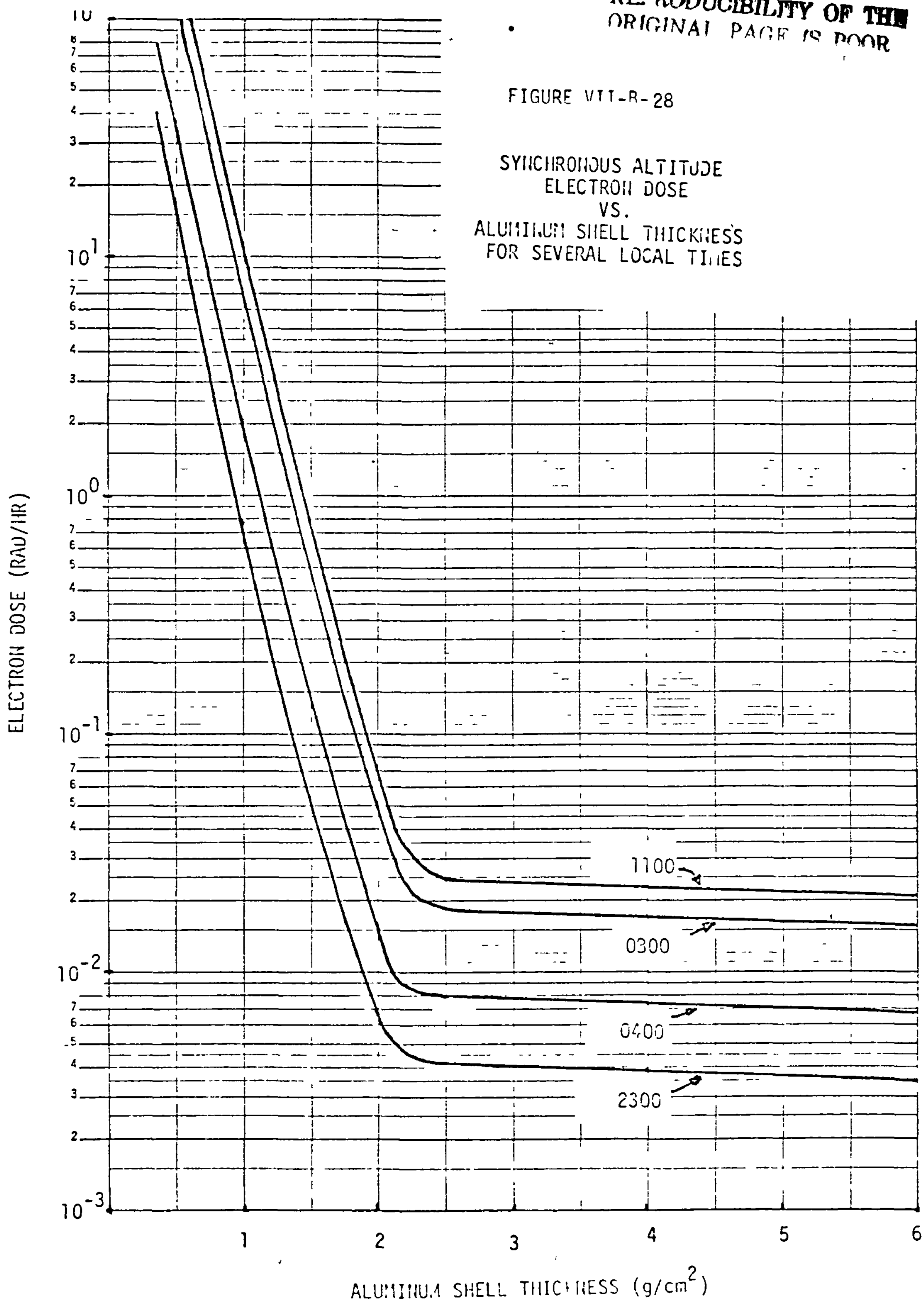
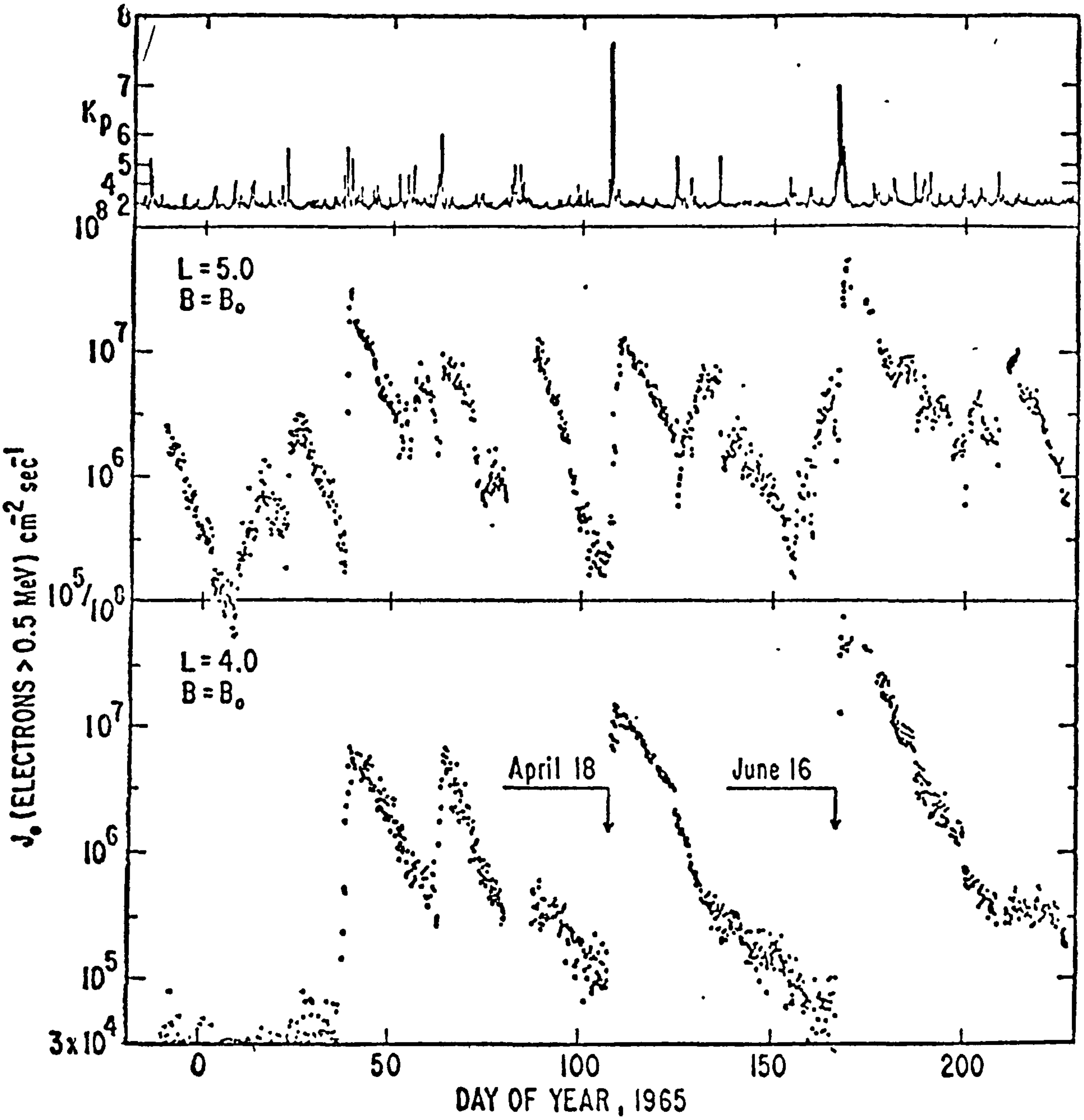


FIGURE VII-B-28
SYNCHRONOUS ALTITUDE
ELECTRON DOSE
VS.
ALUMINUM SHELL THICKNESS
FOR SEVERAL LOCAL TIMES
ELECTRON DOSE (RAD/HR)
ALUMINUM SHELL THICKNESS (g/cm²)
1100
0300
0400
2300
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6



The measurements have been converted to the equatorial flux values The 3-hour magnetic index, Kp, is at the top of the graph. Intense magnetic storms occurred on April 18 and June 16, 1965.

FIGURE VII-B-29 Omnidirectional Flux of Electrons Greater than 0.5 MeV as a Function of Time in the Outer Zone (Taken from McIlwain, 1966)

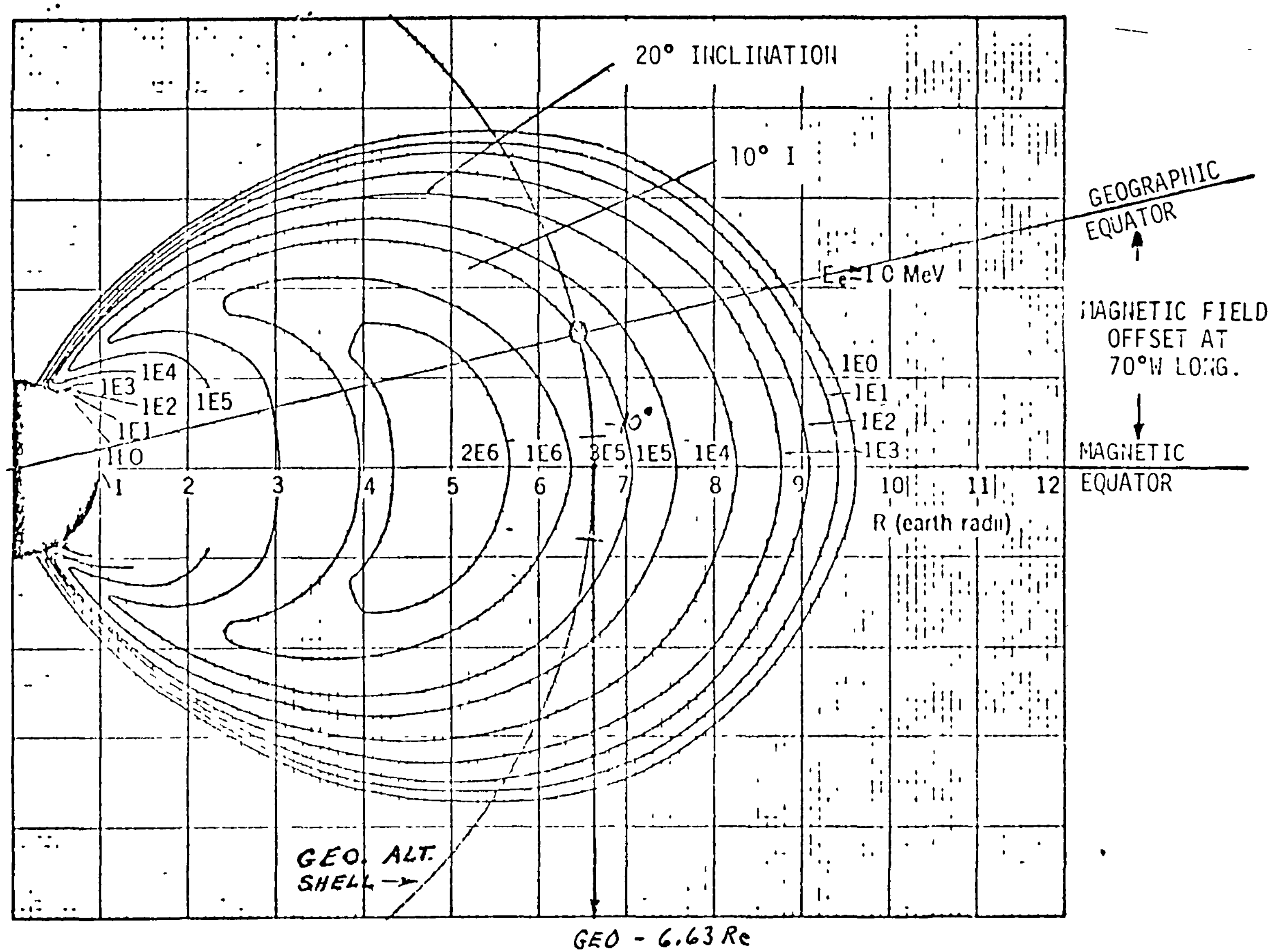


FIGURE VII-B- 30 MAP OF AE-4 ELECTRON FLUXES FOR EPOCH 1964,
THRESHOLD ENERGY 1.0 MeV PLOTTED ON THE
GEOMAGNETIC AND GEOGRAPHIC COORDINATE SYSTEMS
($3E5 \equiv 3 \times 10^5 e^-/cm^2$ - sec.)

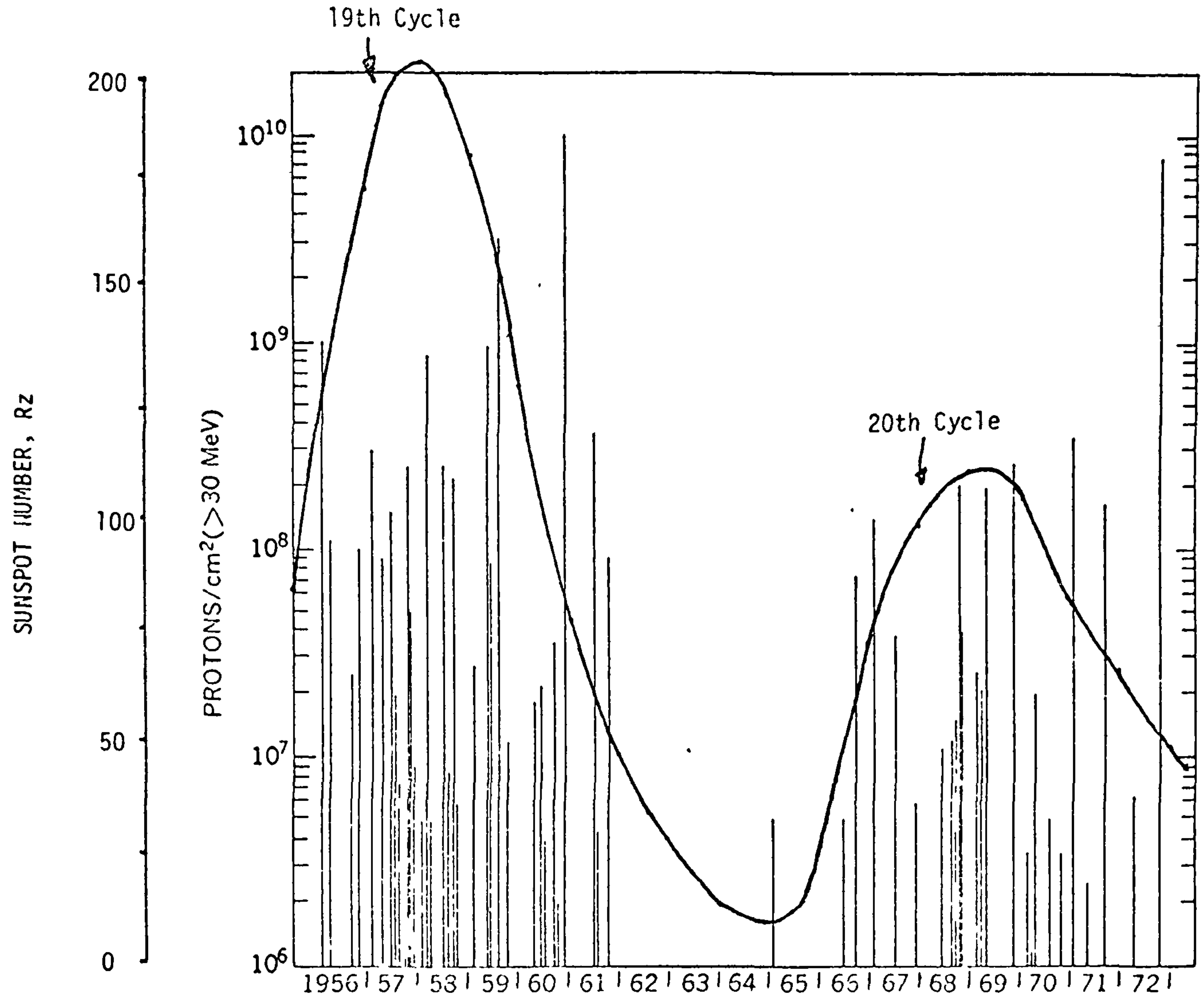
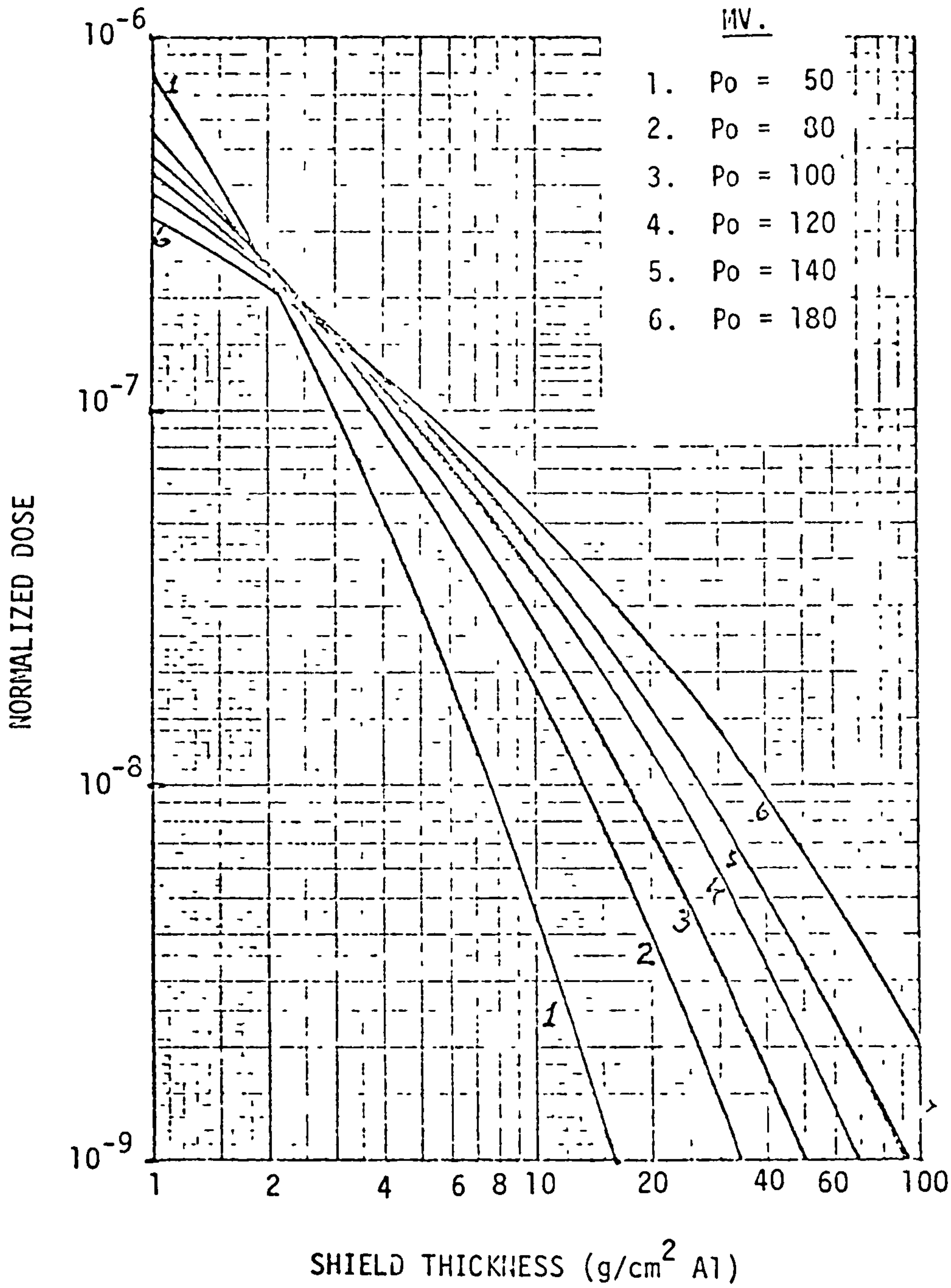


FIGURE VII-B-31 Event-integrated proton fluxes above 30 MeV for the major solar events of the 19th and 20th solar cycles.*

*Ref. 12.

FIGURE VII-B-32



DOSE PER PROTON ≥ 30 MeV AS A
FUNCTION OF THICKNESS AND SPECTRA

FIGURE VII-B-33

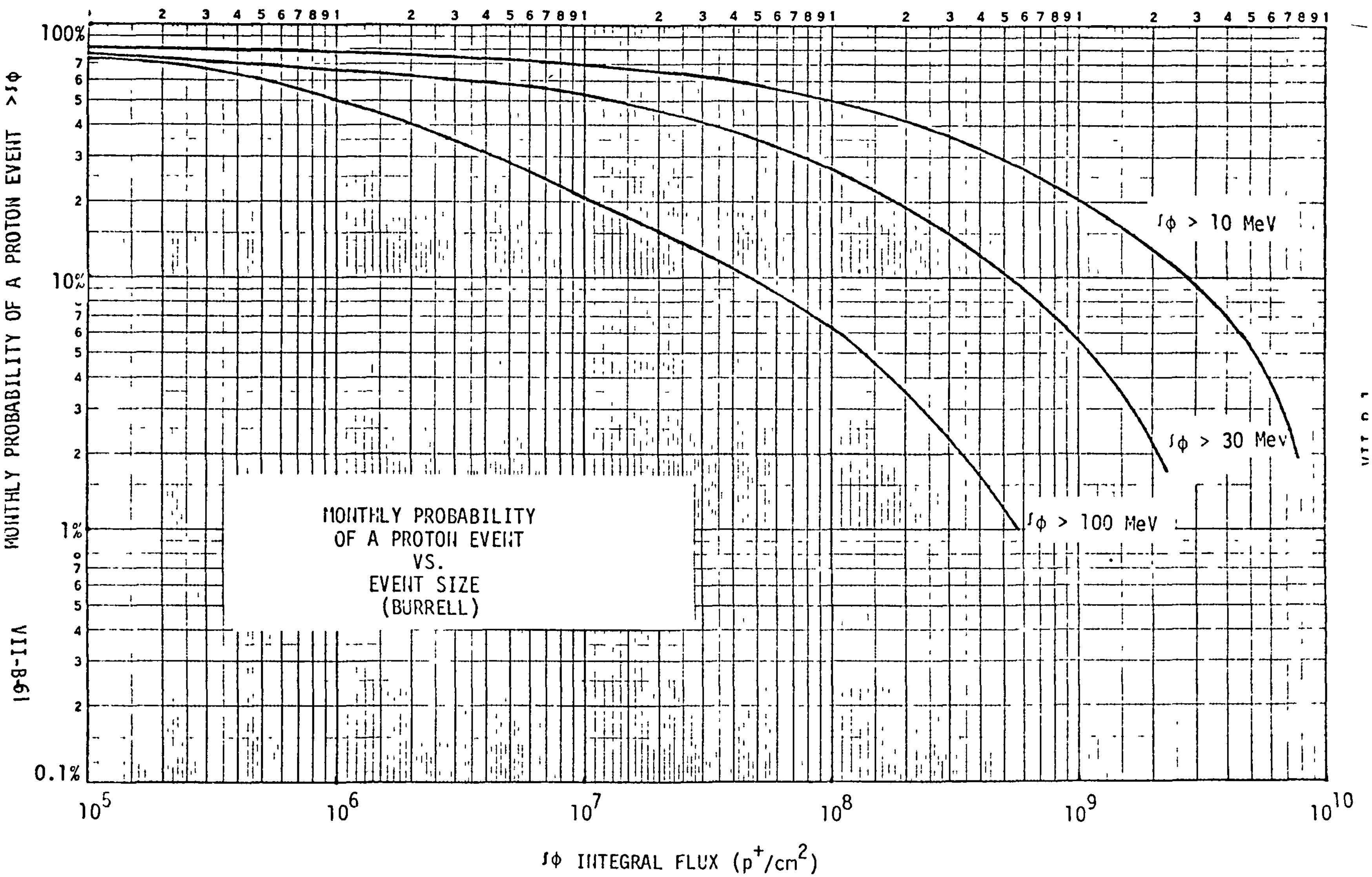


TABLE VII-B-5 TOTAL ESTIMATED SOLAR FLARE DOSES BY EVENT FOR TEN SHIELDING CONFIGURATIONS

	Shielding Configuration									
Date	1/0*	2/0	5/0	10/0	20/0	1/5	2/5	5/5	10/5	20/5
2/23/56	280.00	181.00	91.80	50.20	24.80	64.78	58.00	43.75	30.40	17.90
8/3/56	8.50	5.00	2.20	1.00	0.40	1.39	1.21	0.85	0.53	0.27
1/20/57	122.00	43.50	8.30	1.80	0.30	3.42	2.57	1.23	0.46	0.11
8/29/57	77.00	25.10	4.20	0.80	0.10	1.63	1.20	0.54	0.19	0.04
10/20/57	18.50	10.30	4.10	1.80	0.70	2.53	2.17	1.46	0.88	0.41
3/23/58	148.00	53.60	10.90	2.50	0.40	4.67	3.55	1.75	0.69	0.17
7/7/58	150.00	53.70	10.50	2.30	0.40	4.38	3.30	1.60	0.61	0.15
8/16/58	23.70	8.60	1.80	0.40	0.10	0.75	0.57	0.28	0.11	0.03
8/22/58	45.00	14.90	2.50	0.50	0.10	0.96	0.71	0.32	0.11	0.02
8/26/58	75.00	23.10	3.40	0.50	0.10	1.19	0.85	0.36	0.11	0.02
5/10/59	470.00	211.10	59.30	18.30	4.40	30.18	24.28	13.60	6.70	2.10
7/10/59	420.00	214.00	73.20	27.40	8.40	41.56	34.65	21.76	11.84	4.80
7/14/59	650.00	284.50	75.90	22.30	5.00	37.56	30.00	16.75	7.80	2.50
7/16/59	382.00	194.80	67.20	25.30	7.80	38.30	31.98	20.16	11.03	4.50
9/3/60	13.00	7.20	2.90	1.20	0.50	1.77	1.52	0.10	0.06	0.03
11/12/60	484.00	269.60	105.50	44 90	16.20	64.53	55.12	36.87	21.83	10.05
11/15/60	288.00	151.90	55.90	22.40	7.50	30.04	27.91	18.14	10.33	4.49
11/20/60	17 30	9.50	3.60	1.50	0.05	2.14	1.82	1.20	0.69	0.31
7/12/61	25.70	8.40	1.40	0.30	0.03	0.54	0.40	0.18	0.06	0.01
7/18/61	128.00	64.20	21.60	8.00	2.40	12.16	10.11	6.30	3.39	1.35

* Shielding configurations are given as X/Y where X = shielding thickness in g/cm^2 of aluminum and Y = shielding thickness in g/cm^2 of tissue.

TABLE VII-B-6   20th SOLAR CYCLE EVENT DOSES (RAD)

EVENT DATE	Shielding Configuration (g/cm^2 Al / g/cm^2 TISSUE)							
	1/0	2/0	5/0	10/0	1/5	2/5	5/5	10/5
07-07-66	2.90	1.06	0.21	0.05	0.09	0.07	0.03	0.01
09-02-66	54.22	16.03	2.22	0.35	0.77	0.55	0.23	0.07
01-28-67	70.24	29.96	7.69	2.23	3.73	2.96	1.63	0.72
05-24-67	28.69	7.19	0.75	0.09	0.23	0.15	0.05	0.01
12-03-67	2.73	1.24	0.35	0.11	0.18	0.15	0.08	0.04
06-09-68	9.11	1.95	0.16	0.01	0.04	0.03	0.01	-
09-28-68	6.46	2.56	0.58	0.15	0.26	0.20	0.11	0.04
10-31-68	11.32	2.84	0.30	0.04	0.09	0.06	0.02	0.01
11-18-68	113.20	44.76	10.13	2.60	4.59	3.56	1.85	0.75
12-04-68	25.36	8.22	1.33	0.25	0.50	0.37	0.16	0.05
02-25-69	8.30	4.98	2.27	1.14	1.50	1.32	0.95	0.61
03-30-69	5.64	3.20	1.32	0.61	0.83	0.72	0.50	0.30
04-12-69	121.90	41.46	7.28	1.46	2.87	2.13	0.98	0.34
11-02-69	116.50	55.27	16.98	5.86	9.07	7.44	4.47	2.22
01-31-70	1.63	0.73	0.20	0.06	0.10	0.08	0.05	0.02
03-06-70	1.29	0.19	0.01	-	-	-	-	-
03-29-70	7.51	4.22	1.72	0.78	1.07	0.93	0.64	0.38
07-23-70	0.78	0.10	-	-	-	-	-	-
08-14-70	4.73	0.79	0.04	-	0.01	0.01	-	-
11-05-70	2.56	0.68	0.08	0.01	0.02	0.02	0.01	-
01-24-71	199.00	71.62	13.83	3.05	5.75	4.33	2.09	0.77
04-06-71	1.80	0.49	0.06	0.01	0.02	0.01	-	-
09-01-71	67.14	33.64	11.32	4.26	6.35	5.30	3.32	1.75
05-28-72	4.09	1.37	0.23	0.05	0.09	0.07	0.03	0.01
08-04-72	1111.00	600.00	237.80	103.30	144.80	124.00	83.44	48.53

TABLE VII-B-7

PERCENTAGE OF 19th CYCLE AND 20th CYCLE LARGE SOLAR PROTON EVENTS WHICH DID NOT EXCEED VARIOUS LEVELS OF ALLOWABLE QUARTERLY DOSE TO BLOOD FORMING ORGANS

Shielding g/cm^2, Al	Percent of BFO Quarterly Allowable Doses						
	10	20	30	40	50	100	200
2	69	80	83	85	85	93	98
5	78	83	85	87	89	94	98
10	81	87	89	94	94	98	100

BASED ON 54 EVENTS WITH $\phi \geq 30$ MeV GREATER THAN 10^6 protons/cm^2

VII. ENVIRONMENTAL FACTORS

B. IN-SPACE OPERATIONS

VII-B-2. Energetic Particle Precipitation

Owen K. Garriott
Space and Life Sciences Directorate

Solar cell and reflector degradation from energetic electrons and protons trapped in the earth's magnetic field has been identified as a major source of power loss for the SPS. This is especially true when transferring through the highly populated Van Allen belts from LEO to GEO. Damage in transit can be minimized by temporarily reducing the population of energetic particles on the magnetic shell on which the SPS is currently located.

This study contract has the objective of investigating how well energetic electrons can be scattered into their "loss cone" and thereby "precipitated" from the radiation belts. This scattering is produced by generating a very low frequency (VLF) radio wave which propagates along the magnetic field line in the "whistler" mode. This circularly polarized wave propagates only at a frequency below the local electron gyro frequency. When the radio wave encounters an energetic particle spiraling along a magnetic field line in the opposite direction from the wave, the particle sees an upward Doppler shift of $(v_{\parallel}/\lambda_m)$ where $v_{\parallel}$ is the particle velocity along the field direction and λ_m is the VLF wavelength in the plasma. For resonance to occur, the particle gyro frequency equals the Doppler-shifted wave frequency:

$$f_h = f + (v_{\parallel}/\lambda_m)$$

The study has already shown that this resonant condition can be readily achieved for most energetic particles, in fact, a single encounter of a VLF wave pulse with a reasonable distribution of energetic particles may scatter as much as 7% of the total population into the "loss" cone, after which they never return to high altitudes.

The study will continue to explore optimum frequencies and time variations of frequency to use for precipitation, time constants for loss and replenishment, the desired amplitudes of VLF waves (effects are very non-linear), the degree to which the population of an entire shell of particles may be reduced, and possible ways to precipitate energetic protons.

The work commenced in April, 1977, for one year on a $15,000 contract to the Radioscience Laboratory at Stanford University.

VII-B-3 Space Collision Probabilities

D.J. Kessler
Environmental Effects Office

The NORAD radar is currently tracking about 4000 objects in orbit around the Earth. The smallest size that can currently reliably be tracked is about 10 cm in low Earth orbit (LEO) and several meters in geocentric orbit (GEO). Fig. VII-B-34 compares the collision frequency of the SPS from these 4000 satellites with the collision frequency from 1 gm meteoroids. The dashed line shown at GEO results from an attempt to predict the number of 10 cm objects in GEO. This figure is consistant with the results of a number of other calculations (references 1 and 2), and it can be concluded that the collision frequency from 4000 satellites is represented here to within a factor of 2.

The uncertainty in the collision hazard results from two unknowns: (1) the number of orbiting objects of size 1 mm, and larger, in the year 1990 and later, (2) the consequence of the resulting collisions. The resolution of these two issues will then allow a proper trade-off between design constraints and operations directed toward minimizing the frequency of collision.

Fig. VII-B-35 illustrates the uncertainty in the collision frequency in the year 2000 during the phases of SPS construction, transit, and operation, and is the result of a preliminary modelling effort (ref 3). The lower limits of 11, 6, and 5 during each phase assumes the number of satellites does not increase from its present number. However, during the last two years the number has been increasing at the rate of 510 per year. The "expected" number of impacts results from assuming that this trend continues, some collisional fragments have been generated from satellite collisions, and the current number of satellites is actually 50% more than detected by radar. The expected number in GEO is also the result of estimating the number of 10 cm objects at this distance. However, over the last 10 years, the number satellites has been increasing at the rate of 13% per year, and the upper limits 200, 100, and 900 for 10 cm impact during each phase are obtained. In addition, as the results of collisions between satellites, an even larger number of 1 cm and 1 mm fragments may be produced. An upper limit for their collision frequency is also shown. Thus, the uncertainty in collision frequency ranges over a 4 orders of magnitude in the year 2000. As the flux of even smaller fragments is estimated, and as the date of estimation increases, the uncertainty in the estimate also increases.

The damage resulting from these impacts could be insignificant, if design precautions are taken. In LEO, the average collision velocity is about 10 km/sec. At this velocity, a 1 mm particle (possibly even a .01 mm particle) can easily penetrate a solar cell. However, the area of solar collectors lost from 100,000 1 mm impacts could range from 1×10^{-7} % to 1×10^{-3} %, if the damage is confined to the immediate impact area. The area lost from 100 impacts of 10 cm and larger satellites would be larger, between 1×10^{-4}% and 1%, if the damage is confined. In GEO, the average collision velocity will be much less, probably about 0.1 km/sec.

The mechanics of collisions at this speed are much different than hyper-velocity impact mechanics, and will require a different analysis.

The problem of minimizing the loss of solar collection area is also related to crew safety. The secondary ejecta from solar collector impacts can present a hazard to the crew. Thus another reason for minimizing the amount of this ejecta. However, most probably the primary hazard to the crew will either come from meteoroids or small (1mm to 1 cm) space debris from other satellites. The meteoroid flux is sufficiently well known that design precautions, similar to that used for Skylab, could now be defined; however, the definition of the debris flux in the year 1990 and later is uncertain and could exceed the meteoroid flux.

To resolve these issues, the following tasks are required:

1. Construct a time dependent space debris model. This model would consider all sources and sinks of satellites, such as launch, explosive fragments, collision fragments, orbital decay, re-entry, and retrieval. This model would be used to predict the future debris environment, the uncertainty in the environment, and methods of altering the environment.

2. Improve the data base. Detection of satellites from ground based radar is essentially limited to objects larger than about 10 cm across (reference 4). This limit could be lowered to 1 cm by using a ground based optical system, and to 1 mm by using a space based optical system (reference 5). Other space based concepts which were developed to study meteoroids could also provide valuable data. However, just a close look at the size distributions resulting from explosions and collisions combined with the modelling efforts could do much toward reducing the uncertainty in the predicted flux of small debris.

3. Define the structures necessary to minimize the loss in SPS solar collection area. Much data has been collected on the consequences of hypervelocity and low velocity collisions, much of which can be applied to SPS/debris problems. This data indicates that thin solar collectors will minimize area loss. However, because of the uniqueness of the SPS design and the size of the space debris some testing will be required.

4. Define structure requirements for crew safety and other critical surfaces. Once the environment is defined, sufficient impact data probably already exists to define the shielding requirements for crew safety and other critical surfaces.

5. Consider the trade-offs between debris "clean-up" and design constraints. An early implementation of certain operational and design constraints on the current methods of space activities could lead to a significant reduction in the later debris flux. The later these constraints are implemented, the more difficult it may be to recover to a lower debris flux. Thus, the trade-offs between implementing these constraints and meeting more rigid design goals must be considered as early as practical in order to maintain all options.

References

1. Anon. "Solar Power Satellite: Analysis of Alternatives for Transporting Material to Geosynchronous Orbit", NASA Grant NGT 44-005-114, Oct. 15, 1976. pp 60-70.

2. Anom. "Solar Power Satellite, System Definition Study" Part I. Midterm briefing, March 9, 1977, NAS9-15196, Boeing Aerospace Company, pp. 444-459.

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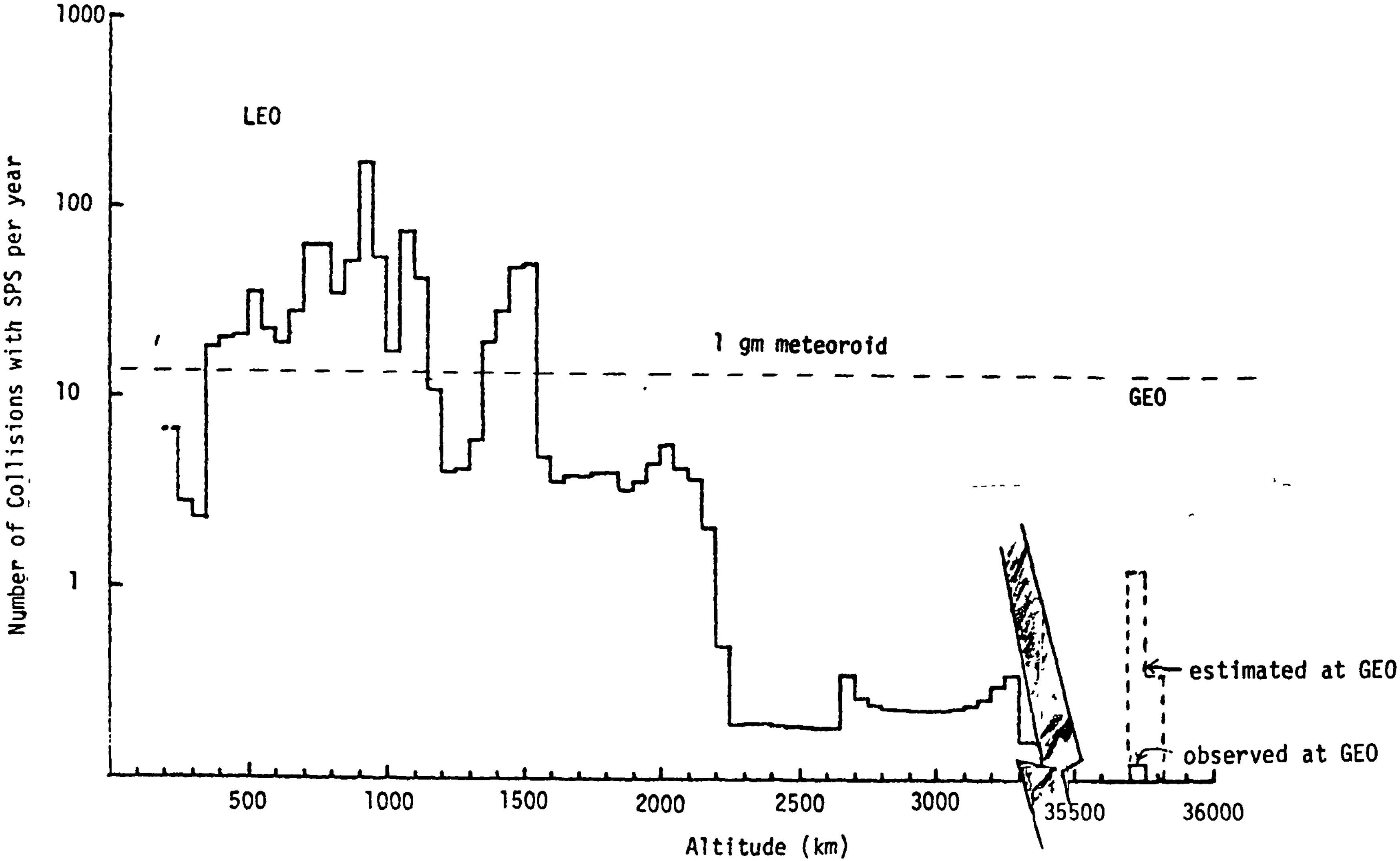


Fig. VII-B-34 Current Distribution of Satellites in Earth Orbit as Observed by Radar. A total of 3866 satellites are in the April, 1976 catalogue, and are represented here.

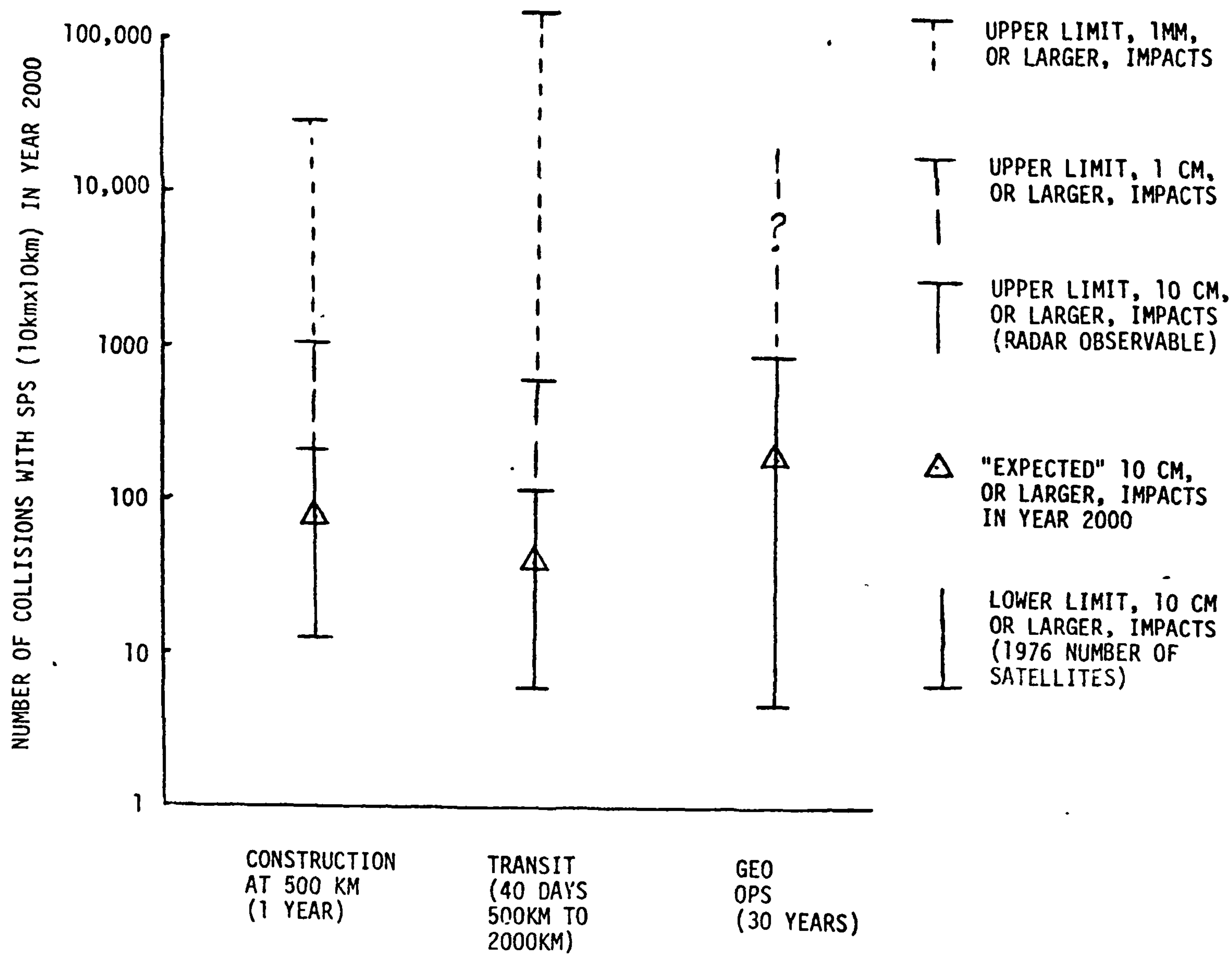


Fig. VII-B-35 UNCERTAINTY IN COLLISION FREQUENCY BETWEEN SPS AND DEBRIS

VIII. MANUFACTURING, NATURAL RESOURCES, TRANSPORTATION AND ENERGY CONSIDERATIONS

INTRODUCTION

The primary purpose of the past year's work under the heading of Manufacturing, Natural Resources, Transportation and Energy Considerations has been to examine in more detail the following:

- Aluminum requirements primarily used in the rectenna.
- Callium supply for potential replacement of silicon solar cell to a gallium arsenide solar cell.
- Surface transportation of fuel to launch site.
- Energy payback for SPS weight ranges.

Finally, a discussion on the energy payback and its relationship to fossil versus non-depletable fuel SPS electrical power plants is briefly discussed.

A. NATURAL RESOURCES

VIII-A-1. Rectenna Aluminum Materials Usage

Harmon L. Roberts
Systems Evaluation Off.

During the past year a study has been conducted to review the structural design of the rectenna. One of the reasons for conducting this study was to reexamine the large quantity of aluminum required and determine if this quantity, resulting in a 7 percent demand for aluminum in the U. S. in the year 2000, could be reduced. This study is reported in Section IV-D-3. of the report. Aluminum is used in this design for power transmission in the rectenna and is an integral part of the structure. This power transmission requires a major portion of the aluminum demand for an SPS program; however, in the year 2000, assuming installation of four 5 Gw rectennas, the U. S. demand requirement would be reduced from 7 percent to 2 percent.

VIII-A-2. Gallium Resource Supply

Jerry C. Poradek
Systems Evaluation Off.

SUMMARY

Although gallium arsenide solar cell technology is in early stages of development, several potential advantages over silicon cells have been identified. These advantages are: higher electrical conversion efficiencies, shorter light absorption paths leading to thinner cells, and lower radiation damage potential. These advantages all tend toward smaller, lighter solar cell arrays. The single major known gallium arsenide cell disadvantage is the lack of gallium available for cell production. The following report

addresses the amount of gallium required for the SPS program and the availability of gallium from the two major sources, aluminum ore and flyash. The amount of gallium needed for the SPS program and the amount available are highly dependent upon numerous supply and demand factors. Therefore, all conclusions on the number of satellites which can be supplied depend upon the following factors:

1. Total number of SPS's proposed.
2. Satellite output power.
3. Solar cell efficiency.
4. Overall satellite system efficiency.
5. Supply source.
   a. Aluminum ore
   b. Gallium concentration in the ore
   c. Coal flyash
   d. Gallium concentration in the flyash
6. Projections on demand or availability of the various sources.
7. Collection efficiencies for the above sources.
8. Extraction efficiency for the various sources.

The following table serves to illustrate the problem in choosing parameters and corresponding results. Amounts of aluminum ore and coal flyash are projected U. S. requirements.

Percent extraction from aluminum ore	10	25
Percent of aluminum ore collected	100	100
Percent extraction from flyash	30	40
Percent of flyash collected	25	30
Gallium concentration in coal	4.6 ppm	6.6 ppm
	U.S. Average	Eastern U.S. Coal
Number of 10 Gw SPS 10 micrometer thick cell	22	55
Number of 10 Gw SPS 5 micrometer thick cell	44	110

SUMMARY CONCLUSIONS

Several significant conclusions can be drawn from the investigations.

1. Widely varying amounts of available gallium can be projected based on differences in supply, extraction efficiency and collection efficiency.

2. If emphasis is placed on gallium recovery it appears that in excess of 100,000 MT of the metal can be produced from U. S. coal/flyash and U. S. required aluminum ore from friendly countries by 2025.

3. GaAs solar cells must approach the 5 to 6 micrometer thickness level to allow for production of 112 satellites in the 10 Gw range with the gallium available above.

GLOSSARY OF TERMS

SATELLITE OUTPUT POWER: Power delivered to the national power grid by an SPS.

SOLAR CELL EFFICIENCY: The fraction of energy converted from solar to electrical energy by a solar cell.

EXTRACTION EFFICIENCY: The amount of gallium extracted from an ore source compared to that which was originally available in the source.

COLLECTION EFFICIENCY: The amount of gallium source material collected for gallium extraction compared with the amount of source available in a given year; i.e., if 10 X 10^6 MT of flyash were scrubbed from stack gases of electric generation plants in a given year, but only 2 X 10^6 MT were collected and sent to a gallium extraction plant the, collection efficiency would be 20 percent.

GALLIUM RESOURCE SUPPLY

1.0 Introduction

The purpose of this study is twofold; first to define the magnitude of gallium demand for use in Solar Power Satellite (SPS) program when various parameters relating to gallium arsenide (GaAs) solar cells are identified. Further, as a result of known demands, this study attempts to define the range of the amount of extractable gallium available to the United States from various sources. Specific topics covered include:

a. Gallium demand with variations in efficiencies, cell thickness, solar concentration and satellite number.

b. Gallium availability from zinc and aluminum production.

c. Projected coal usage for electric power generation.

d. Gallium available from coal usage.

e. Projections of most probable factors in GaAs solar cell use in Solar Power Satellites.

2.0 General Background for SPS Gallium Demand

In the analysis of the SPS, the weight of the satellite has a major effect on all other elements, such as fuel, number of launches, ground facilities, ground transportation, natural resources and pollution. The

major weight element in the SPS as it is presently envisioned, is the solar cell array.

Silicon solar cells are presently proposed as the leading candidate for the SPS array based on their current advanced state-of-development. Several drawbacks to the use of silicon include: (1) comparatively low electrical conversion efficiency; (2) low light absorption coefficient; (3) large cell thickness; (4) moderate sensitivity to proton and electron damage; and (5) large efficiency degradation at increased temperatures.

A gallium arsenide solar cell, although in early stages of development and with several negative aspects of their own, shows potential improvements in the following areas:

(1) Because the absorption coefficient is high, a thin crystal cell can produce a high conversion efficiency cell.

(2) A thin crystal cell would significantly reduce array weight, even though GaAs has a high specific gravity of 5.34.

(3) Because thin cells are practical, the potental damage from electron and proton damage is reduced.

(4) Temperature effects which reduce electric conversion efficiency appear at this time to be much less severe in GaAs than in silicon cells.

If in the next decade the GaAs cell can be developed to a degree approaching the expectations of some researchers, the only major problem confronting its incorporation in an SPS program would be the availability of the gallium to produce the GaAs solar cells. The availability problem is addressed in parametric form in the following section.

2.1 SPS Gallium Demand Factors

The amount of gallium arsenide required in the SPS program is directly dependent on a number of factors which include:

(1) Number of satellites required.

(2) Thickness of GaAs required for the cells.

(3) Efficiency of the photovoltaic conversion of the cell.

(4) Efficiency of all the other operations in the power train such as: spacecraft power distribution, antenna power distribution, DC-RF conversion, phase control, mechanical alignment, atmospheric absorption, rectenna energy collection, RF-DC conversion, power interface and power conversion to the electrical grid.

(5) The amount of solar concentration designed into the system.

2.2 Gallium Demand Nomograph

Because these factors cannot be defined at this time, and even the range of the numbers is open to conjecture, this paper introduces a nomograph to cover a wide range of possible variations in the independent variations in the independent variables.

Cell Conversion Efficiency (Column 1)

Cell electrical conversion efficiency is dependent upon various parameters such as cell material, thickness, purity, temperature and cell structure defects. Some of these factors are determined at the time of design and others during operation, the operating environment, and the operational lifetime. A definition of these factors cannot now be ascertained for GaAs cells in 1995 time frame, but in column 1 of the Nomograph VIII-A-1, any operational cell efficiency from one to 100 percent can be assumed.

System Efficiency (Column 3)

The various element efficiencies in the SPS affect the final overall efficiency directly. In column 3, the efficiency for all other SPS and ground units is identified. Again, any efficiency from one to 100 percent is available on the nomograph.

Overall Efficiency (Column 2)

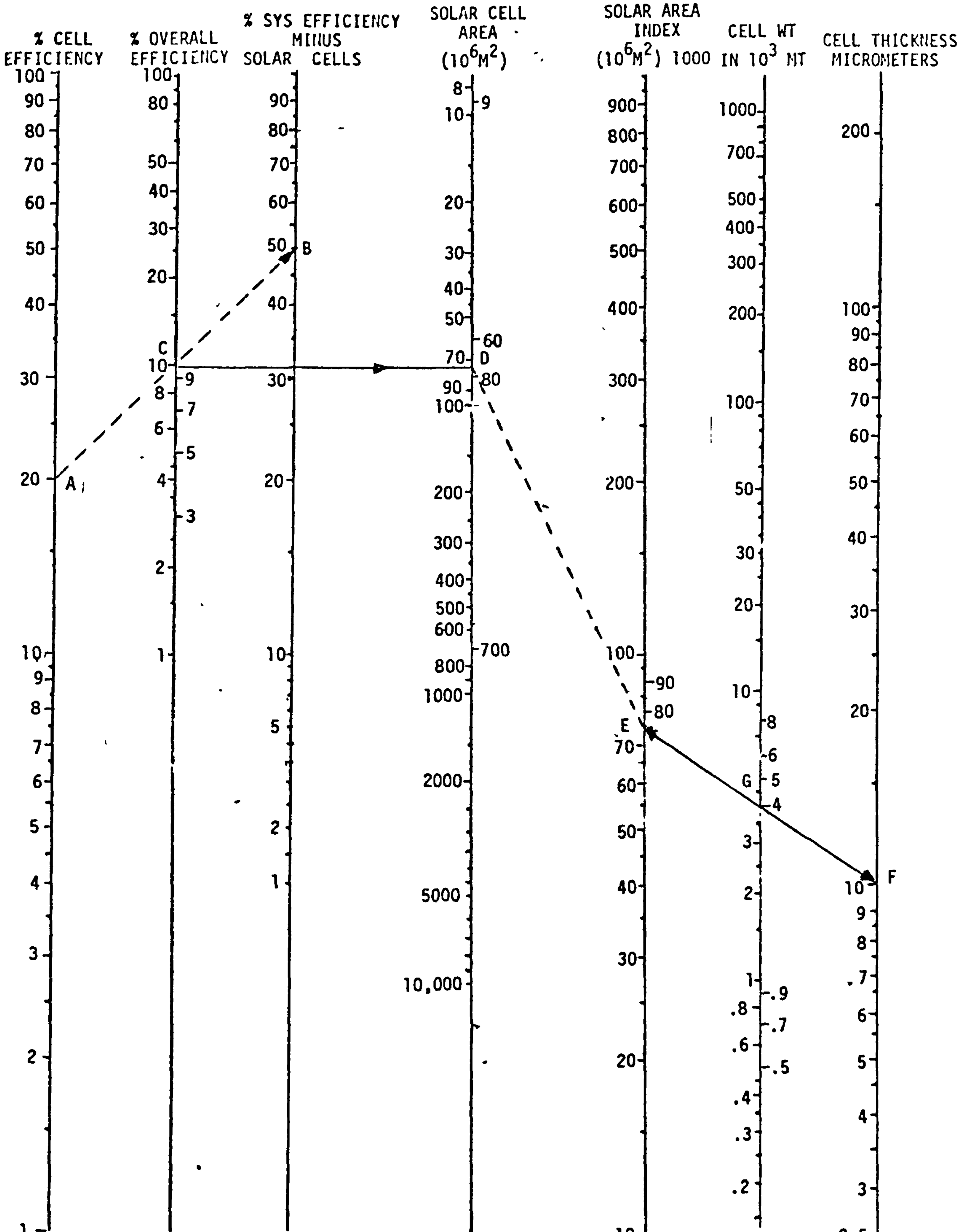
By drawing a line connecting the cell (column 1) and satellite efficiencies (column 3), the overall efficiency is defined at the line intersected in column 2. This figure represents the percent of energy introduced to the power grid which is incident to the satellite cell surface.

Satellite Cell Area, Column 4 and Cell Area Index, Column 5

Drawing a line horizontally from the overall efficiency, column 2 to column 4, will define the total area of cells required for a 10 Gw SPS with no solar concentration. For ease of calculation, the column figures are inverted and expanded to column 5, the solar area index. At this point the cell thickness in micrometers is determined and set in column 7. Connecting the desired thickness (column 7) with the cell area (column 5) the total cell weight in 1000's of metric tons as defined in column 6.

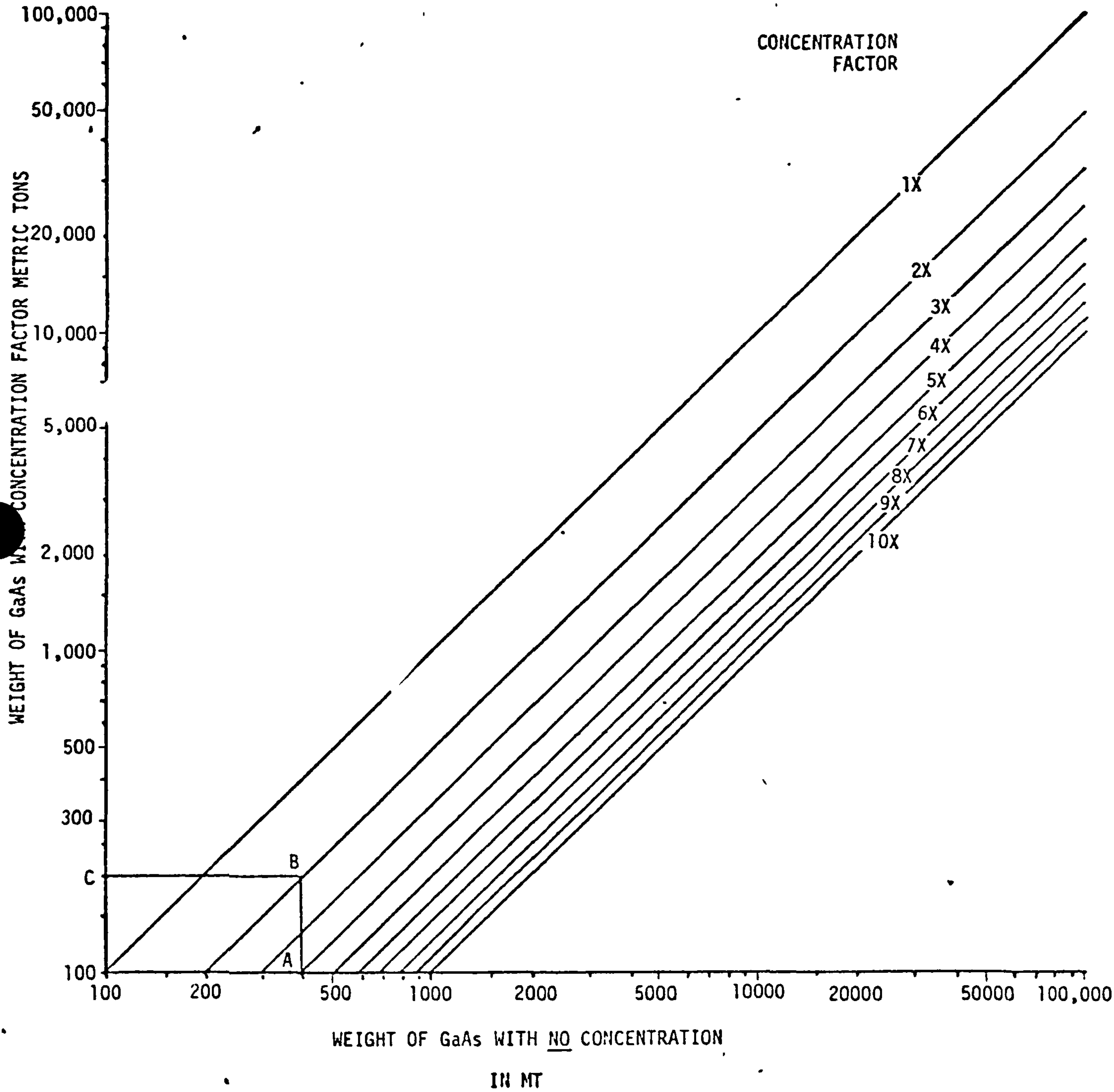
Concentration Factor

Moving to Graph VIII-A-1., with the weight of solar cells from Nomograph VIII-A-1., the total weight of cells can be determined based on concentration ratios. This determines the weight of GaAs required for one satellite. The equivalent weight of gallium is then found on Graph VIII-A-2., which then defines the gallium demand per satellite.

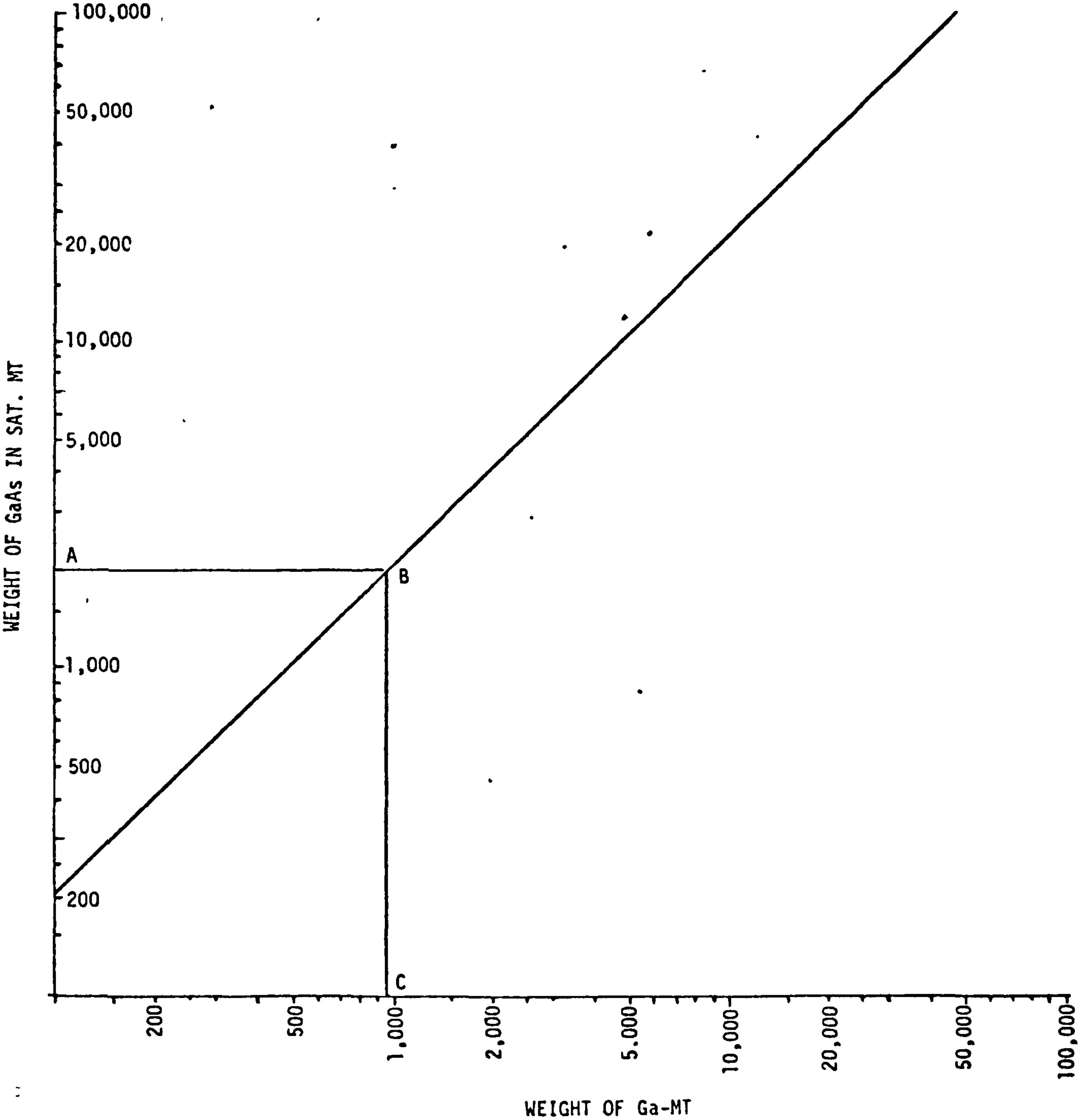


NOMOGRAPH VIII-A-1

GRAPH VIII-A-1



GRAPH VIII-A-2



3.0 General Background for SPS Gallium Supply

The limiting factor in gallium arsenide production is the amount of economically producible gallium arsenide available. Gallium itself is plentiful, about 45×10^{10} metric tons within the continental United States and another 7×10^{9} metric tons in sea water; however, in general, the concentrations are too small to be economically retrievable. Estimates of gallium concentration in ocean water range up to about 5 ppb and continental crust concentration up to 18 ppm. Only in a few major ores is the concentration of Ga high enough to make extraction feasible and then the economics are valid only when the ore is mined for another primary metal such as Zinc Sulfide (Ga concentration $\approx$ 50 ppm) and Bauxite (Ga concentration $\approx$ 100 ppm, average).

One other potential source has been identified, coal. The amount of Ga in coal itself is not high, ranging from about 3 to 7 ppm, but nearly all of the gallium is volatilized in the combustion process and is then recrystalized on the surface of the coal flyash as cooling takes place in the exhaust stack. Under normal circumstances, the average range of flyash gallium concentration is between 50 and 100 ppm. The concentration of gallium in coal decreases from east to west in the United States. This fact and the estimated amount of Ga potentially available from U. S. coal deposits is shown in Table VIII-A-1. Figure VIII-A-1 shows projected use of coal for electric power generation.

3.1 SPS Gallium Supply Factors

The amount of gallium arsenide which can be supplied to the SPS program is directly dependent on the available gallium, which is dependent on several factors outlined below:

(1) The amount of gallium potentially available from zinc ore.

(2) The amount of gallium potentially available from aluminum ore.

(3) The amount of gallium available from coal flyash.

(4) The collection efficiency for gathering the ore tailings and flyash.

(5) The recovery efficiency from the various extraction processes.

3.1.1 Gallium from Zinc and Aluminum (Zn and Al)

Zn: Gallium can be extracted from the ores of both Zn and aluminum. Concentrations of gallium in Zn ores range from 0.001 to 0.02 percent and averages about 0.005 percent. The amount of gallium available is about 0.0022 percent that of the Zn available. Zn production in 1968 for the United States was about 1.6×10^{6} MT. Thus, a theoretical yield of gallium would be 35 metric tons. By the turn of this century, Zn production should range between 2.23×10^{6} MT and 4.27×10^{6} metric tons, which could yield between 49 to 94 MT. Present known U. S. Zn reserves indicate a total of 700 MT of gallium is extractable and some 5000 MT total available from world Zn reserves.

Table VIII-A-1 GALLIUM CONTENT OF UNITED STATES COAL

Eastern Province

State	% Gallium in Ash	% Ash	ppm of Ga in Coal
Alabama	.0055	9.2	5.06
E. Kentucky	.0099	7.3	7.22
Maryland	.0020	9.5	1.90
Ohio	.0050	11.8	5.90
Pennsylvania	.0071	10.0	7.10
Tennessee	.0057	9.7	5.52
Virginia	.0085	7.8	6.63
W. Virginia	.0077	8.5	6.54
	.0064	9.2	5.73
Average.................	.0071	9.3	6.60

Interior Province

State	% Gallium in Ash	% Ash	ppm of Ga in Coal
Arkansas	.0025	8.3	2.07
Illinois	.0035	11.7	4.09
Indiana	.0035	10.6	3.71
Iowa	.0070	15.5	10.85
Kansas	.0020	10.5	2.10
Missouri	.0065	12.4	8.06
W. Kentucky	.0040	9.3	3.72
	.0041	11.2	4.59
Average.................	.0039	10.5	4.09

Western States

State	% Gallium in Ash	% Ash	ppm of Ga in Coal
Arizona	.0050	9.7	4.84
Colorado	.0032	9.2	2.92
Montana	.0039	12.6	4.91
New Mexico	.0034	11.8	4.01
North Dakota	.0020	12.0	2.40
Utah	.0030	7.0	2.10
Washington	.0059	12.7	7.49
Wyoming	.0017	8.7	1.47
	.0035	10.5	3.67
Average.................	.0033	9.8	3.23
National Average by State	.0047	10.3	4.66
National Average All Samples	.0048	9.9	4.64

Average .0093 # of Ga/Ton of Coal at 4.65 ppm Ga Concentration in Coal
107.53 tons of Coal/# Ga

C-8

Al: The calculation of gallium from aluminum follows the same rationale, except that the ratio of gallium to aluminum is one to 4000 or 0.025 percent. A 1968 production rate of 4.0 million MT of aluminum would yield 1025 MT of gallium. By 2000, the aluminum demand will range from 20.4 to 40.4 million MT. Various projections on the amount of recycling indicate from 16.3 to 32.2 million tons will come from ore. This could yield between 4075 and 8075 MT of gallium per year. Total U. S. reserves of aluminum, however, are estimated at only 9 million MT and could yield no more than 2250 MT of domestic gallium. Considering estimated western world resources of some 875 million MT, the total yield of gallium is 218,750 MT if 100 percent recovery is assumed.

3.1.2 Gallium from Coal

Gallium is found in trace amounts in all coals, but the amount found is not enough to warrent extraction from the coal. However, as the coal is burned, the gallium is volitalized and oxidized. As the gallium is converted to Ga_2O_3, it begins to condense because the high oxide boiling point is greater than the combustion temperature. The Ga_2O_3 condenses on the solid particles suspended in the gas stream and is trapped by the flyash condensing system. By collecting all the gallium in the flyash, the gallium in the coal is concentrated from 20x to as much as 150x, depending upon the type of coal and the type of firing system.

Several techniques for extracting the gallium from the coal flyash have been devised. Tests to evaluate the amount of gallium available in U. S. coal deposits have been conducted. In general, the concentration of gallium decreases from east to west across the United States. Eastern coal averages about 6 ppm gallium; the interior section averages about 4 ppm, and about 3.25 ppm of gallium is found in western coal. The national average of 4.6 is used in this paper. Figure VIII-A-2 shows the amount of gallium recovery potential from the projected coal demand for electric generating plants between now and 2025.

4.0 Collection Efficiency in Accumulating Ore Tailings and Flyash for Gallium Processing

This efficiency will vary with the source. The extraction of Zn and Al from ore is already done on a large scale at smelters. This means that gallium extraction can be done at the smelter also and nearly 100 percent of the gallium bearing ore should be available for the extraction process.

In the case of coal flyash, however, only very large plants or groups of plants in close proximity to each other could support the cost of an efficient extraction plant. Thus, a large portion of the flyash will not be accumulated for extraction.

FIGURE VIII-A-1 COAL DEMAND FOR ELECTRIC POWER GENERATIONS

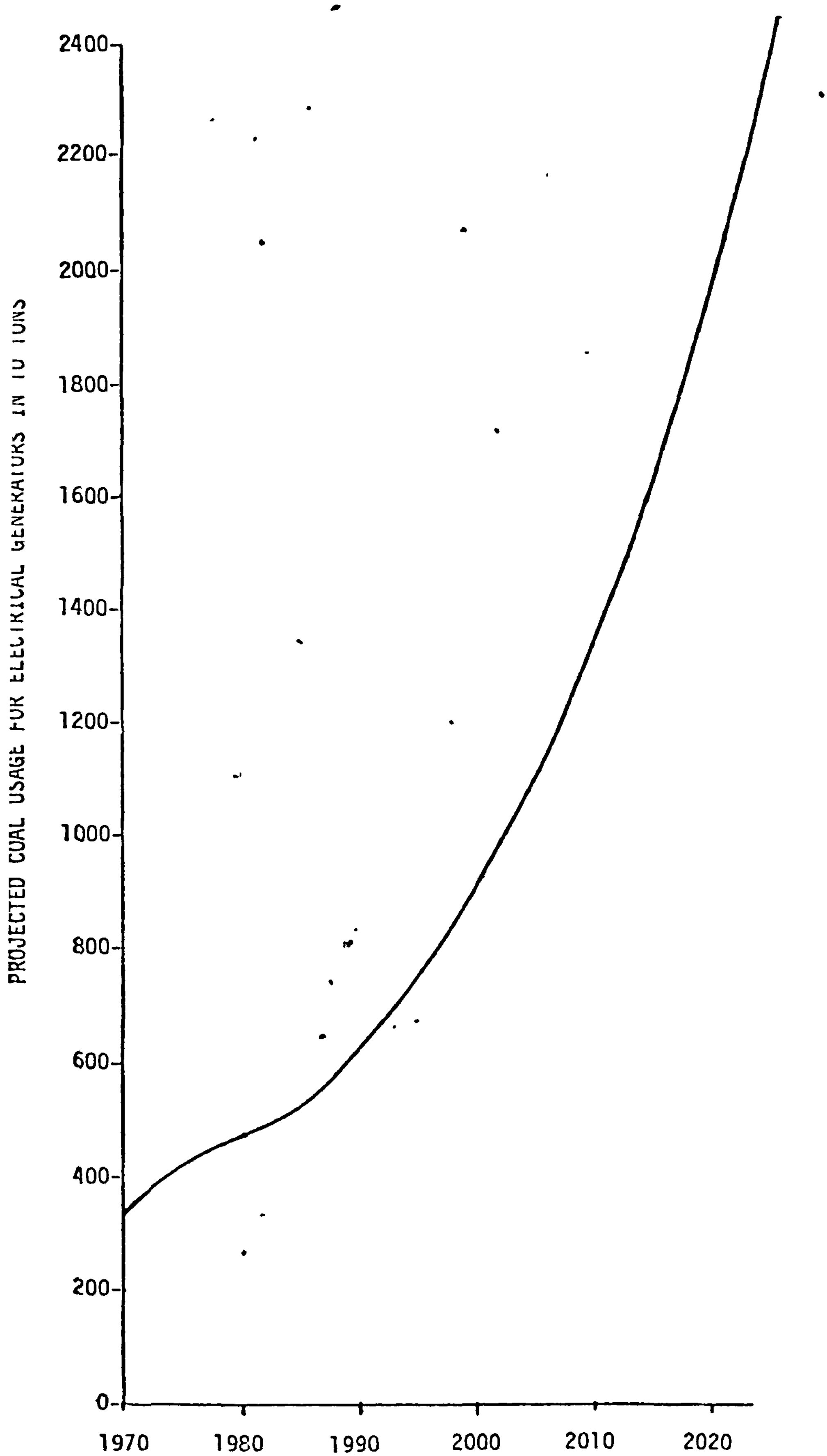
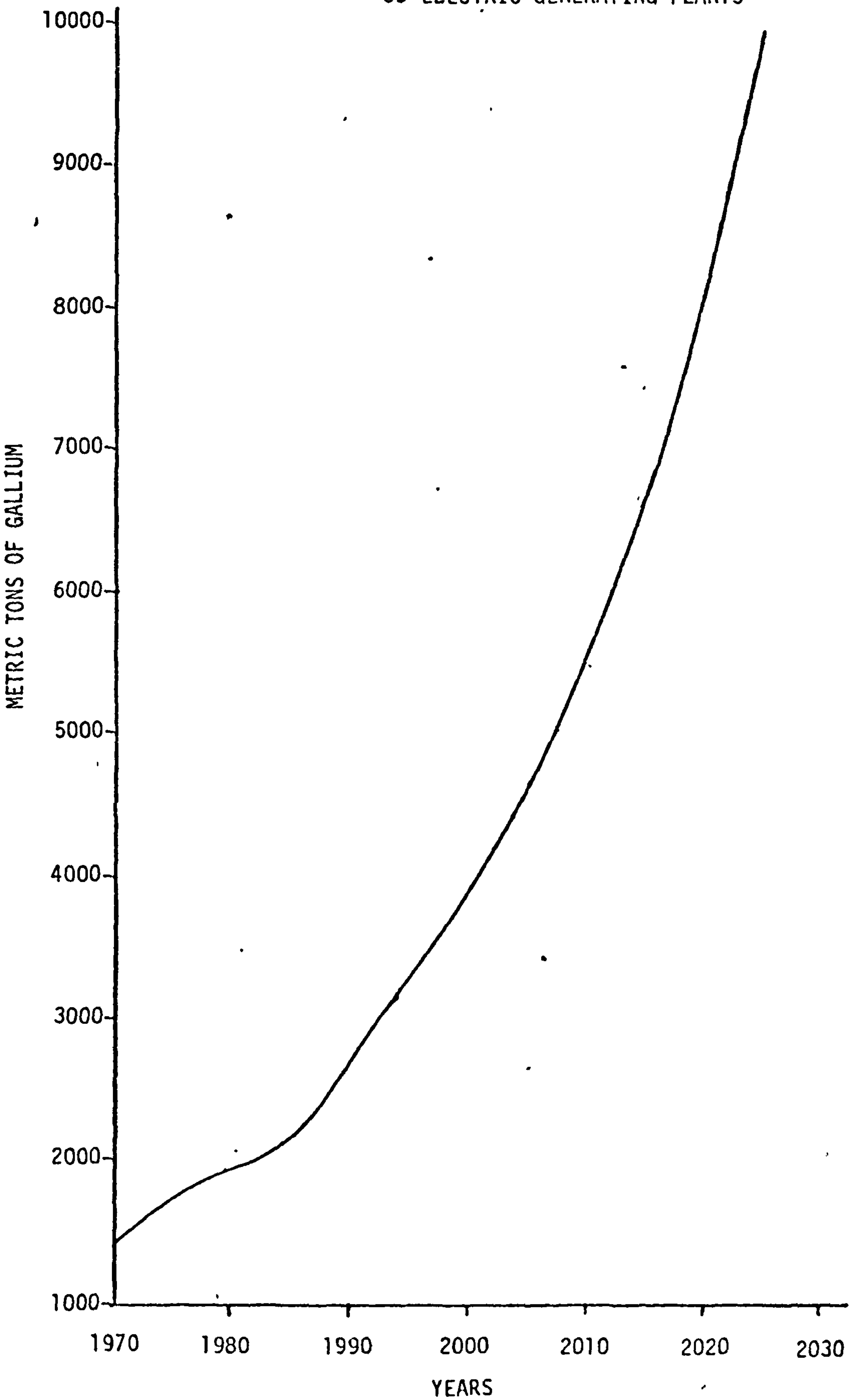


FIGURE VIII-A-2 GALLIUM AVAILABLE FROM COAL
US ELECTRIC GENERATING PLANTS



5.0 Extraction Efficiency

Extraction techniques vary widely in efficiency. Because such low concentrations of gallium are available in even the best cases, the extraction efficiency will not approach 100 percent. Low efficiencies can be expected initially with improvements made as experience is gained. Though large amounts of gallium are available from aluminum bearing ore, the extraction efficiency presently is low, being about 10 percent. Without a major processing breakthrough, this percentage should remain low although collection efficiency of the ore should approach 100 percent. However, new extraction techniques yielding efficiencies of over 20 percent are being developed at this time.

Extraction from coal flyash is more efficient, about 30 percent, but the ability to economically collect high percentages of flyash is questionable. Present estimates of collection range from 10 to 40 percent efficiency in flyash collection. Collection efficiency is dependent upon the desire for the gallium and if more gallium was required the amount of flyash collected could be adjusted accordingly.

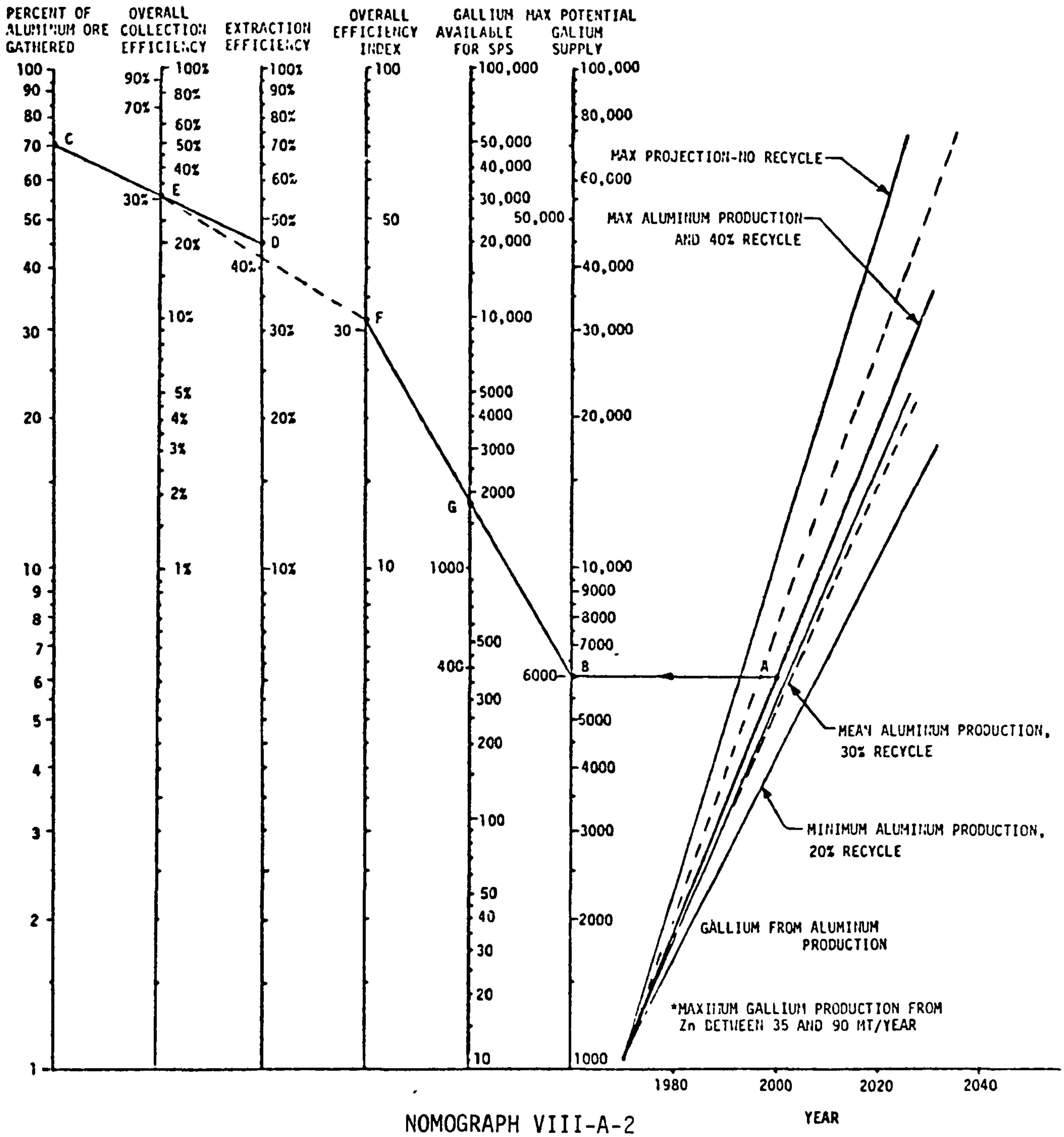
6.0 Gallium Supply Nomographs

Zn and Al

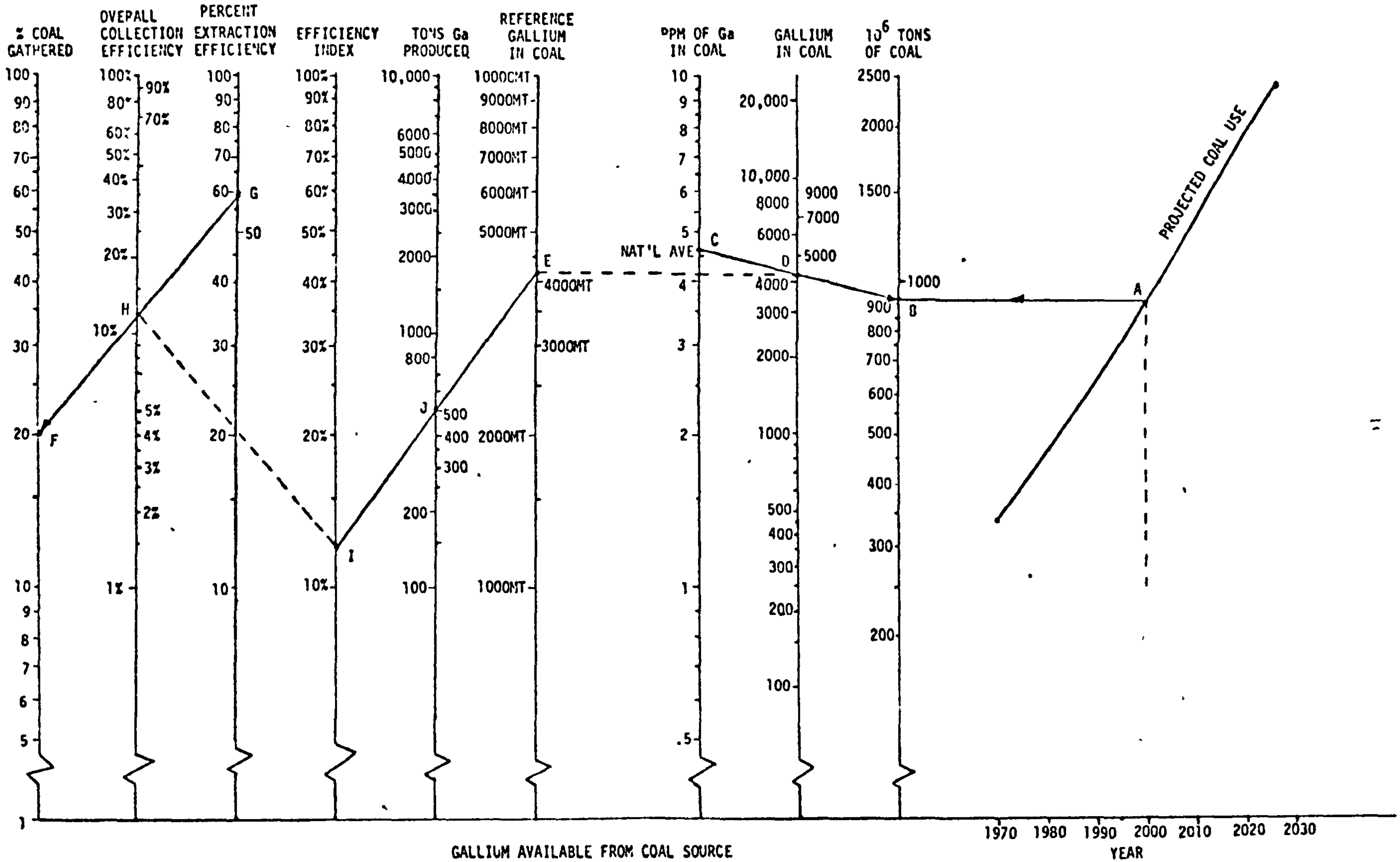
Nomograph VIII-A-2 shows the projected maximum amount of gallium from Al refining for the years to 2025. The curves can be neglected and column 6 used directly, if desired. Once the desired amount of maximum gallium potential is selected (column 6), proceed to column 1 and work to the right. Column 1 is the percentage of available ore that undergoes gallium extraction. Column 3 is the percentage of gallium that can be recovered by the extracting process. Column 2, between the two, is the overall recovery efficiency. Project that point to the efficiency index (column 4) line to the same numerical value. Draw a line from the efficiency index through column 5 to the maximum potential gallium supply point previously selected on column 6. The amount of recovered gallium read in column 5. Zinc ore will produce 35 to 90 MT per year, and is ignored for purposes of SPS gallium supply. It could be used to supply other gallium requirements.

Coal

Nomograph VIII-A-3 can be used to identify the amount of gallium available from coal for SPS usage knowing certain variables. A curve defining the projected use of coal for power plants is shown to the right of column 9. The amount of coal for any year is chosen by assuming a year and moving vertically to the line intercept. Moving left horizontally to column 9, defines the amount of coal available. In column 7, identify the ppm concentration of gallium in the coal. Column 8 intersection defines the amount of gallium in the coal. Define this amount on the gallium in coal index, column 6. At this point, proceed to column 1 and estimate the percent of coal flyash which is



NOMOGRAPH VIII-A-2



NOMOGRAPH VIII-A-3

collected for processing of gallium and choose the percent extraction efficiency in column 3. Connecting these two points identifies the overall collection efficiency of column 2. Translate this value to the efficiency index line, column 4. The intersection of a line connecting the values in column 4 and 6 with column 5 will define the amount of gallium recovered from coal.

7.0 Gallium Stockpiling

Table VIII-A-2 indicates the kind of gallium availability based on stockpiling of the gallium before the actual SPS requirements. The table shows the yearly and accumulated totals between 1980 and 2025 A.D. The supply is based on the collection extraction efficiencies of 10 percent from aluminum ore and 30 percent from coal flyash with collection efficiency of 100 percent for aluminum ore and 25 percent for coal flyash. Supply of ore and ash is based on coal use and aluminum demand. The nomographs project the minimum expected demand for the gallium source. It can be seen that the stockpiling of gallium in the 1980's does not have a significant effect on the overall amount collected. Only about 10 percent of the total is collected in this period because the projected demand is low compared to the post 1980's.

8.0 Example

8.1 Gallium Demand, Nomograph VIII-A-1

In this example, a cell efficiency of 20 percent is set in column 1, point A. A 50 percent remaining system efficiency is assumed in column 3, point B. Drawing a line between these points, crosses column 2 at point C. Moving from point C, horizontally to column 4, yields a solar cell area of 75 X $10^6 m^2$ at point D. Next, translate D to column 5, point E at 75 X $10^6 m^2$. Assuming a cell thickness of 10 micrometers in column 7, point F, and connecting points E and F yields an answer of 4000 MT at point G, column 6.

Moving to Graph VIII-A-1, and inputing 4000 tons on the horizontal line (point A) and moving up to the 2x diagonal line, define the GaAs required for a satellite with a concentration of 2 (point B). Moving laterally to the left margin yields a weight of 2000 MT at point C. Place the weight of GaAs on the left margin (point A) of Graph VIII-A-2, and move horizontally to the diagonal line (point B) and move vertically to the lower margin, point C and read the amount of Ga required; 950 MT per satellite.

8.2 Gallium Supply for Aluminum Production (Nomograph VIII-A-2)

The maximum amount of gallium potential in 2000 is 6050 tons (point A). Move to column 6, point B. Identify the percentage of Al which has gallium collection incorporated, say 70 percent (point C, column 1), an extraction

Table VIII-A-2 GALLIUM STOCKPILING

Year	Gallium from Al.	Gallium from Coal	Total Ga	Cum. Collect
1980	160	220	380	380
1981	170	223	939	773
1982	180	227	407	1180
1983	190	230	420	1600
1984	200	234	434	2034
1985	210	237	447	2481
1986	220	241	461	2942
1987	230	244	474	3916
1988	240	248	488	3904
1989	250	251	501	4405
1990	260	255	515	4920
1991	274	260	534	5454
1992	288	265	553	6007
1993	302	270	572	6579
1994	316	275	591	7170
1995	330	280	610	7780
1996	344	285	629	8409
1997	358	290	648	9057
1998	372	295	667	9724
1999	386	300	686	10410
2000	400	305	705	11115
2001	424	312	736	11851
2002	448	319	767	12618
2003	472	326	798	13416
2004	496	333	829	14245
2005	520	340	860	15105
2006	544	347	891	15996
2007	568	354	922	16918
2008	592	361	953	17971
2009	616	368	984	19855
2010	640	375	1015	19830
2011	680	382	1062	20932

Table VIII-A-2 (cont'd)

	Gallium from Al.	Gallium from Coal	Total Ga	Cum. Collect
2012	720	390	1110	22042
2013	760	397	1157	23199
2014	800	405	1205	24404
2015	840	412	1252	25656
2016	880	420	1300	26956
2017	920	427	1347	28303
2018	960	435	1395	29698
2019	1000	442	1442	31140
2020	1040	450	1490	32630
2021	1092	465	1557	34187
2022	1144	480	1624	35811
2023	1196	495	1691	36502
2024	1248	510	1758	39260
2025	1300	525	1825	41085

efficiency of 35 percent can be expected in the early program and 45 percent by 2000 (column 3, point D). Read 31.5 percent on column 2, point E. Find 31.5 percent on index line, column 4, point F. Connect point B and F and read SPS available gallium in column 5, point 6 (1850 MT).

8.3 Gallium Supply from Coal (Nomograph VIII-A-3)

The amount of coal forecast to be used in the year 2000 is shown in point A of graph. Moving horizontally to column 9 reads 915 X 10^6 tons at point B. Using the national average of 4.6 ppm (point C, column 7) indicates a maximum potential of 4200 MT for the year. Locate this value on the gallium in coal index, column 6, point E. Proceed to column 1 and find the chosen value of 20 percent, point F. An extraction efficiency of 60 percent is chosen at point G, column 3. Column 2 indicates the overall efficiency of 12 percent at point H. Translate the 12 percent figure to point I in column 4, the efficiency index. Connecting points E and I locates point J, the tons of gallium produced from coal in column 5. This amounts to 510 MT of gallium. Taking the two hypothetical cases in Nomograph VIII-A-2 and VIII-A-3, the total gallium collected would be:

Aluminum - 1850 MT

Coal - 510 MT

Total......2410 MT

Matching the demand from Nomograph VIII-A-1, gallium SPS demand example would require 950 MT/satellite or 2400 MT = 2.5 satellites are available from the gallium supply.

9.0 Anticipated Limits

By 2000 the various constraints on the use of gallium arsenide, which this paper addresses, will be fairly well defined. As projected at this time, those variables have the following limits.

Demand	Maximum	Minimum	Most Probable
Cell (%)	22	12	18
System Efficiency other than Cells (%)	70	40	58
Overall Efficiency (%)	15.4	4.8	10.4
Solar Cell Thickness (micrometers)	20	3	5
Concentration (X)	10	2	2
Supply			
Aluminum			
Supply (10^6 MT)	40.4	20.4	30.4
Percent Recycle (%)	50	10	30
Collection Efficiency (%)	100	10	100
Extraction Efficiency (%)	90	5	30
Overall Collection Eff. (%)	90	0.5	30
Coal			
Supply (10^6 Tons)	1200	600	912
Collection Eff. (%)	75	10	30
Extraction Efficiency (%)	90	10	40
Average Extraction Coal Gallium Concentration (ppm)	6.6	3.2	4.5
Overall Collection Efficiency (%)	67.5	1.0	12

10.0 Conclusions

The use of gallium arsenide solar cells in the SPS requires certain significant developments.

- Advancement of GaAs solar cell technology to the point where 5 or 6 micrometer thick, 20 percent efficiency cells can be economically fabricated.

- Improved efficiencies for the gallium extraction processes for both aluminum ore and flyash.

- A carefully planned and operated system for the collection of a significant portion of the U. S. coal flyash, especially from the higher gallium content eastern coal.

- Stockpiling of gallium should begin in the next few years so that the stockpile will lead satellite demand.

B. SURFACE TRANSPORTATION REQUIREMENTS

VIII-B-1. Continental U. S.

W. S. Beckham, Jr.
Systems Evaluation Off.

The objective of the subject task was to define and determine the impact on the nation's industrial transportation and logistics systems caused by implementation of various SPS scenarios as postulated in the JSC study entitled "Initial Technical Environmental and Economic Evaluation of Space Solar Power Concepts," JSC-11568, dated August 31, 1976.

The approach selected was to compare one of the proposed design concepts and implementation scenarios with the latest available data on U. S. commerce to determine, on a percentage basis, the relative magnitude of the task.

The analysis focused on several discreet areas. These areas, which are discussed in detail subsequently, were:

a. Transportation of SPS hardware

b. Ground equipment capacity to handle SPS payloads

c. Propellant requirements and production methodology

The elements and scenarios selected for the comparison included the column and cable SPS design, with a maximum launched weight of 124,292 metric tons (MT), the ballistic/ballistic heavy lift launch vehicle (HLLV) using a LOX/RP-1 first stage and a LOX/LH_2 upper stage with a nominal payload of 453 MT and a cargo orbital transfer vehicle (COTV) using LOX/H_2 as the propellant. Scenario B was chosen for analysis. The two points of the scenario used for sizing were the initial years when the launch rate was one SPS per year and 2024, the busiest year when seven SPS's were launched and maintenance operations required flights equivalent to another 1.12 satellites.

Surface Transportation

U. S. surface transportation takes many forms. To provide the reader with a starting point, Table VIII-B-1 tabulates the cargo capacities of the most common forms of moving equipment available today. Table VIII-B-2 shows the required number of these elements to move the 124,292 MT SPS at the two launch rate extremes selected from scenario B. As can be seen from Table VIII-B-2, only if an all-aircraft system were chosen would there be any significant numbers of vehicles required.

Since the actual launch site location is undefined, sea-borne transportation was chosen and a port was sized to handle the incoming hardware. Water-borne commerce was chosen since (1) it may be mandatory due to site location; (2) truck commerce data includes much short-haul, intercity movement; and (3) cargo sizes may be more compatible with large

TABLE VIII-B-1

TYPICAL TRANSPORTATION CAPACITIES

MODE	CAPACITY (MT)
Truck	36
Train (100-Car)	5,000
Aircraft (747-200F)	121
Ship	45,000
Tanker (VLCC)	450,000

TABLE VIII-B-2

TRANSPORTATION/LOGISTICS

REQUIREMENT/SUPPORT	1 SPS/YEAR	7 SPS + MAINTENANCE
Truck	9.4/Day	77/Day
Train	.067/Day	.55/Day
Aircraft	3/Day	23/Day
Ship	.0075/Day	.06/Day

TABLE VIII-B-3

SPS TRANSPORTATION/IMPACT

Port Sizing

- o Total U. S. Water-borne Commerce (1974) 1583×10^6 MT
- o Port of Houston (1974) 80×10^6 MT
- o Port of Palm Beach, Florida (1974) 1.09×10^6 MT

	One SPS	7 SPS + Maint.
o Total SPS Tonnage*	$.124 \times 10^6$ MT	1.01×10^6 MT
o SPS Percent of Total	0.0078%	0.06%

ships. Table VIII-B-3 shows a comparison of the total SPS hardware to total 1974 U. S. water-borne commerce. On a percentage basis, the SPS hardware represents an infinitesimal portion of 1974 cargo. For reference, the figures for two representative ports are also shown. The maximum SPS hardware rate is less than that handled by the port of Palm Beach, Florida. This port ranked 151st in capacity in the U.S. in 1974.

Ground Handling Equipment

As stated previously, the HLLV payload was selected to be 453 MT. At this time, no attempt has been made to establish the weight of the largest package which may make up this payload. There are in existence mobile cranes of extremely heavy lift capacity. The port of New Orleans, La., has a barge mounted crane capable of lifting 590 MT. All major ports have cranes in the 450 MT class. It is safe to assume that no major advancements are needed in this area to handle SPS components.

Propellant Requirements and Production Methodology

Using the chosen HLLV and satellite designs outlined previously, propellant requirements per satellite was established as follows:

RP-1	1,173,829 MT
H_2	307,619 MT
LOX	4,896,248 MT

For purposes of this analysis, the RP-1 was examined because it utilizes a scarce resource and hydrogen because of its energy intensiveness in comparison to liquid oxygen.

RP-1

RP-1 requirements vary from 1.17 X 10^6 MT for one satellite up to 9.59 X 10^6 MT in 2024. To supply this amount of propellant requires a standard tanker every two weeks for the low rate. At the high rate, only the VLCC (very large crude carrier) class vessel seems practical and the high launch rate will require one of these vessels every 17 days. No U. S. ports can handle this class vessel, so an offshore terminal such as the proposed Seadock facility will be required.

Hydrogen

Hydrogen requirements for the two chosen launch rates are 841 MT per day and 6830 MT per day, respectively. Numerous methods are available to produce hydrogen. Table VIII-B-4 lists several of these processes and the approximate efficiencies associated with each. Although steam reforming and partial oxidation are the most efficient, they use feedstocks which are projected to be in short supply and, for

this reason, were not considered. Coal gasification was examined initially since the U. S. has large resources of coal. Subsequently, electrolysis was examined with the idea of bootstrapping the production of hydrogen utilizing operational SPS units for power. The implications of the two approaches is discussed below.

HYDROGEN PRODUCTION METHODS

METHOD	APPROXIMATE BASE-CASE PROCESS EFFICIENCY
STEAM REFORMING OF NATURAL GAS	0.75
PARTIAL OXIDATION OF OIL	0.65
COAL GASIFICATION	0.55
NUCLEAR/ELECTROLYSIS	0.33
NUCLEAR/THERMOCHEMICAL	0.33*
SOLAR/THERMAL/ELECTROLYSIS	0.33*

*ESTIMATED

TABLE VIII-B-4

Hydrogen Production by Coal Gasification

The basic material and utility requirements for this process are 42 lbs. of coke and 3 kwh of electrical power to produce 1000 scf of 97% hydrogen gas. Since coke production requires 1.43 lb. coal per lb. coke the relationship works out to be 10.78 lb. coal/lbH_2 gas.

Liquification of hydrogen consumes 5.67 kwh/lbH_2. Production of electricity requires approximately .99 lb. coal per kwh. The total process requires approximately 16.88 lb. coal/lbH_2 liquid.

Translating this into the daily demand of the two launch rates gives a coal requirement of 14,198 MT/day and 116,110 MT/day respectively.

A logistics analysis was then performed, assuming a distance of 1500 miles between the mine and the launch site. The first approach analyzed was to place the gasification plant in the vicinity of the launch site since it seemed sensible to transport a stable commodity like coal rather than hydrogen. The transport energy, in terms of coal, worked out to 916 MT/day and 7,440 MT/day respectively. This brought the total coal consumption to 15,124 MT/day and 123,550 MT/day. In terms of rail movements, this amount of coal requires 2.8 and 23 100-car coal trains per day.

Production of hydrogen at the mine site would reduce the coal input back to feedstock requirements only, but would necessitate a 1500-

mile pipeline. Energy requirements for pipeline operation were not determined.

Another major factor in this process is the requirement for process and cooling water, independent of site location. The process water requirements ranged from 17.8 X 10^6 to 144 X 10^6 gal/day. Cooling water requirements were given to be 359 gal/lbH_2. If one assumes a 95% closed system (5% loss) the cooling water requirements are 33 X 10^6 gal/day and 260 X 10^6 gal/day, or a total water input of 50 X 10^6 to 404 X 10^6 gal/day average. For comparative purposes, the city of Houston consumes only 250 X 10^6 gal/day average. Location of the gasification plant might well be dictated by the water requirement rather than the coal supply logistics.

Hydrogen by Electrolysis

In an attempt to avoid the coal logistics problem, the production of hydrogen by electrolysis was examined. In this approach, a bootstrap operation was envisioned; that is, the electrical power for the process was assumed to come from an SPS dedicated for this purpose. The basic utility requirement for this process is given to be 140 to 160 kwh/1000 scf of 99.9% hydrogen gas. This translates to a requirement of 27 kwh/lbH_2 gas. Adding the liquification power of 5.67 kwh/lb. yields a requirement of 32.67 kwh/lbH_2 liquid.

A single 10 GW satellite, operating at a 92% plant factor produces 80.59 X 10^9 kwh/yr. sufficient to produce 11.2 X 10^5 MT/yr. of LH_2.

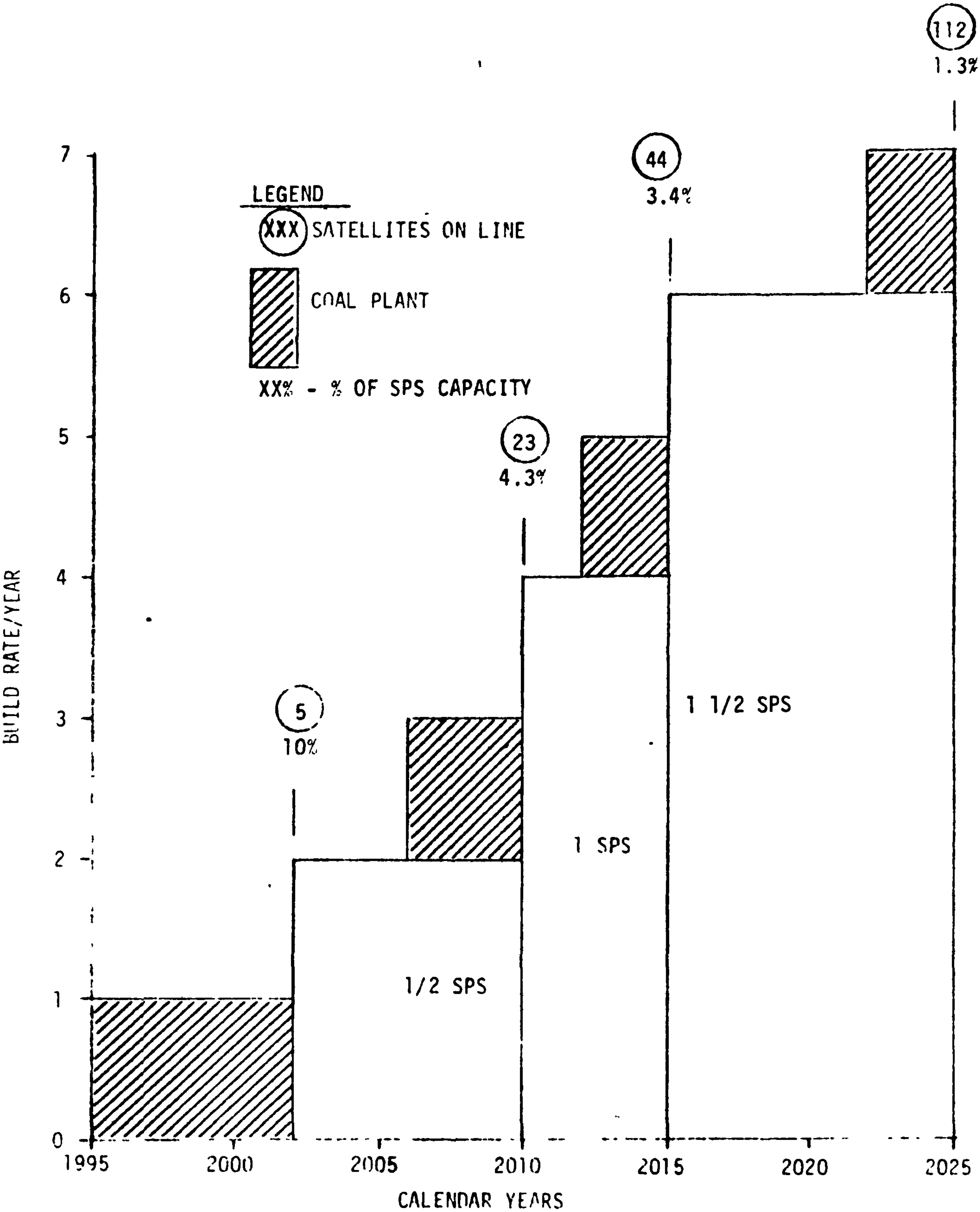
Hydrogen Production Summary

Initial analysis indicates that hydrogen production, in the quantities required, will be a significant driver in the SPS program. Figure VIII-B-1 depicts a potential production method mix for scenario B. In this approach, a gasification plant, sized to support a launch rate of one SPS/yr., is installed. This plant is sufficient to carry the program through the first seven years. At that point, five operational satellites are on station. The plant will require 10% of installed SPS capacity. Electrolysis plants are sized to utilize SPS power in 5-gigawatt (1 rectenna) increments. The coal plant is used for peaking when required. This process if followed throughout the program. Since the operational SPS fleet is growing, the percentage of power diverted for production is a constantly decreasing portion of the power available.

Cost

As noted previously, the electrolysis operation requires 32.67 kwh/lb. of H_2. If the nominal 59 mil/kwh generation cost is met, the process power cost by this method is \$1.92/lb.H_2. Adding \$.12/lb for amortized capital cost, and \$.08/lb for M & O costs, results in a total cost of \$2.12/lb.

COMBINED HYDROGEN SUPPLY SCENARIO



NOTE: ASSUMES MAINTENANCE ACTIVITIES DEMAND MET BY BY EXISTING CAPACITY

Fig. VIII-B-1

Conclusions and Recommendations

The payloads required for SPS, even with high implementation rate and conservative weight estimates, represent a small percentage of 1974 water-borne commerce, keeping in mind that the time frame under consideration is 20-45 years hence and that the water-borne shipments are but a function of total commerce, it is probably safe to assume that their influence on the nation will be minimal. Handling of these payloads also appears to be no problem of significance.

The significant problem associated with the SPS program, insofar as its impact on the U. S. transportation, logistics, and industrial system, will be the production and movement of required propellants and the feedstocks necessary for production. Further investigations into this problem, optimizing the production methodology mix and examing the second order economics, is warranted at this time.

VIII-B-2. Equatorial Launch Considerations

W. L. Gill
Systems Evaluation Off.

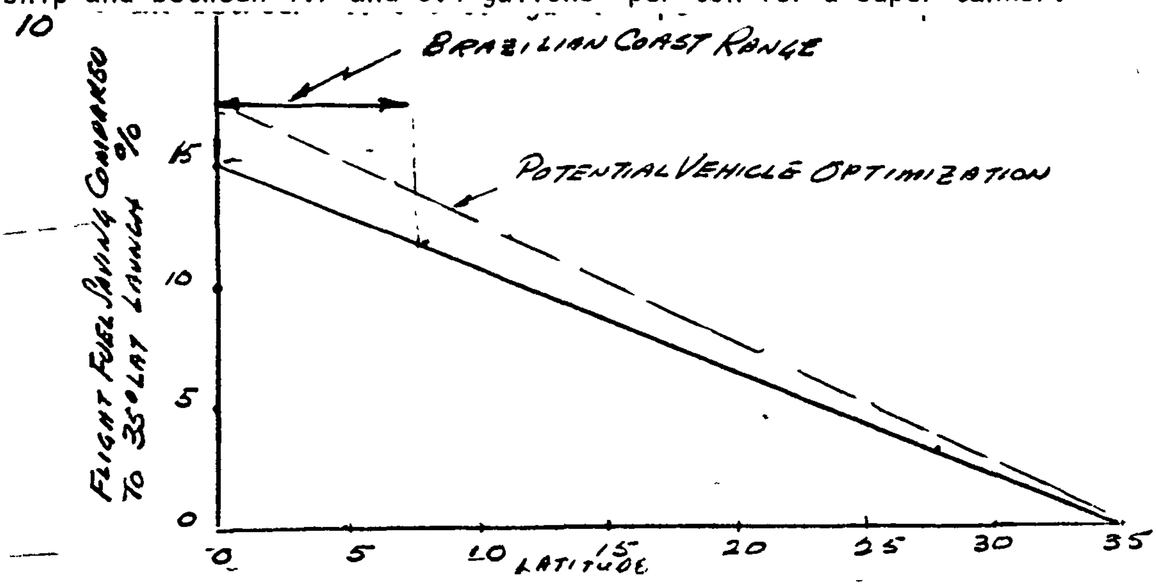
A preliminary study of the advantages and disadvantages of an equatorial launch site has been made.

Parametric Consideration: Plane change fuel saving based on delta-V considerations for an equatorial launch compared to a Cape Kennedy or White Sands launch is approximately 15 percent. Fuel saving is approximately inversely proportional to latitude. Design of a launch vehicle for a specific launch site may permit a second order fuel savings of a percent or so. The transport or material from the continental United States to an equatorial site by surface transportation can be thought of as a zero altitude plane change.

A 15,000 ton container ship will deliver 150 ton miles/gallon of fuel consumed. A 100,000 ton super-tanker will deliver 950 tons miles/gallon of fuel consumed.

The nearest sites to the continental United States on or near the equator suitable for a launch site would appear to be located along the Brazilian coast from the north border to Recife. The distance to be traveled from Cape Kennedy to a launch site in this general area is around 2500 to 3000 miles. Using the delta from above indicates that a container ship will burn between 16.6 and 20 gallons of fuel per ton of cargo to transport supplies from Cape Kennedy to a launch site in Brazil, while a ship the size of a super-tanker would require from 2.6 to 3 gallons of fuel per ton of cargo for the same trip.

A return trip in ballast would require about 80 per cent of the fuel consumed when loaded, making the overall fuel expenditure per ton to an equatorial launch site between 30 and 36 gallons per ton for a container ship and between 4.7 and 5.4 gallons per ton for a super tanker.



For the nominal SPS without growth of mass 54,542 metric ton.

The HLLV propellant requirement is 2.92 X 10^6 metric ton, and the propellant to GEO is 2.983 X 10^6 metric ton. Thus, 53.5 metric tons of propellant are required per metric ton of SPS on station. An equatorial launch which saves 15 percent of the HLLV propellant would save 8.05 metric ton propellant per ton of SPS on station, and at about 7° latitude, this saving would be 6.71 metric ton/SPS ton.

Cape Kennedy Launch	
Propellants for 1 SPS =	2.920 X 10^6
Non Consumables	6.264 X 10^4
TOTAL	2.983 X 10^6

Manufacturing Propellants at the Equator with 15% Fuel Saving and Manufacturing from Coal

Material	Kennedy Flt Mass HLLV MT	Equatorial Flt Mass (Kennedy X .85) MT	Tonne Coal to produce/ Tonne	Cargo of Coal & Oil to be transported to equator MT
LO_x	2.241 X 10^6	1.905 X 10^6	.4786	.912 X 10^6
LH_2	.1403 X 10^6	1.193 X 10^6	12.00	2.316 X 10^6
JP1	.5384 X 10^6	.458 X 10^6	NA	.458 X 10^6
TOTAL	2.919 X 10^6	2.556 X 10^6		3.686 X 10^6

FUEL USAGE RATES/TRIP

Round Trip Fuel Requirements

Surface Transport	Gal/Ton Cargo		Tonne Oil/Ton Cargo		Tonne Coal/Ton Cargo	
	2500 mi. Trip	3000 mi. Trip	2500 mi. Trip	3000 mi. Trip	2500 mi. Trip	3000 mi Trip
15,000 Ton Cargo Ship	30	36	.101	.122	.163	.197
Super Tanker	4.68	5.49	.016	.018	.026	.029
Cargo Jet	167	200	.567	.68	.910	1.10

For Comparison Purposes 1.616 Ton Coal = 1 Ton Oil

Total Fuel Usage for 3.686 X 10^6MT of Coal and Oil + 6.264 X 10^4 Material

or 3.748 X 10^6MT in Coal Equivalents transported to or near the equator.

Total Fuel Required

Surface Transport	2500 mi. Trip	3000 mi. Trip
15,000 Ton Cargo Ship	610,924	738,356
Super Tanker	97,448	108,692
Cargo Jet	3.42 X 10^6	4.122 X 10^6

COAL EQUIVALENT OF PROPELLANTS

LO_x - .912 X 10^6

LH2 2.316 X 10^6

JP1 .740 X 10^6 * as equivalent Coal @ 1.616 Ton Coal/Ton Oil

15% Fuel Saving (equatoriac) = 595,200 MT
12.5% Fuel Saving (7° Lat.) 496,000 MT

Net fuel saving in propellants - surface transport fuel used for 1 SPS

Transport	2500 mi. Trip/eq	3000 mi. Trip/7°Lat
15,000 ton Cargo	-15724	-242356
Super Tanker	497752	387308
Cargo Jet	-2.82 X 10^6	-3.62 X 10^6

Thus to be profitable - very large cargo tankers should be used.

The mass of ground launch facilities to support the operation which must be established at the equator will add to the transport cost, and the supplies required to support the launch facilities will also add to this burden. These include cargo handling facilities at the equatorial site, dedicated surface transport and possibly the expansion of U.S. port facilities to handle expanded surface traffic. These one-time logistical capital costs would indicate that the use of an equatorial launch site is more attractive when such costs can be spread over many SPS. Lead time for construction will also be an important consideration.

Operation Advantages: Multiple launches to the same point in an orbit involves window considerations. If construction is undertaken in an inclined orbit or around 35°, launches to the same point in an orbit would be spaced about 14 hours apart, or about 1.7 launches per day. Some improvement in launch frequency may be possible if the plane change to an equatorial orbit is made prior to construction. For an equatorial launch, windows should be spaced around 90 minutes apart or about 16 launches per day. The heavy launch vehicles being considered for SPS transport to low-earth orbit have payload capabilities of 450,700 and 900 metric tons. For the construction of a single SPS in one year, the launch frequency will be less than one-per-day even for the smallest vehicle so that window considerations should not strongly affect construction schedules. Near the end of Scenario B, the 450 metric ton pay load HLLV will require 16 launches per day to maintain schedule and the 900 metric ton payload HLLV requires 8 launches per day. At that time six SPS's will simultaneously be under construction, and maintenance payloads will account for one additional SPS. Assuming that the construction sites are equally spaced around the same orbit, then launch windows spaced 2 hours apart should supply material to each to meet construction schedules. The launch rate to any one construction site remains less than one-per-day.

Construction of this magnitude being carried out at a high rate over a long period of time requires a high degree of flexibility in launch schedules. The equatorial launch site where rendezvous can be carried out about 1.5 hour has distinct advantages. Near equatorial launch sites may slightly reduce available launch opportunities, but should provide more flexibility than a higher latitude launching site. Based upon last year's report, personnel launches and recoveries are from two to four per cent of the total launches for SPS construction, and there would appear to be a distinct advantage to carrying such launches from a United States site, since there should be extensive medical screening and treatment facilities associated with these operations.

Siting Considerations

If it is estimated that about 4 miles should be the exclusion area around a launch site for a 900 metric ton HLLV, and that around 10 such launch sites are required for maximum Scenario B operations. Launch sites would require around 200 square miles port facilities, payload integration, vehicle checkout and fuel processing living areas, recovery areas, etc.,

would bring overall area requirements to around 800 square miles. If ballistic vehicles are used, a down range recovery area, an exclusion zone in the ocean will be required. The optimum location for such an equatorial launch site would be just north of the Amazon River in Brazil. Other sites in decreasing order of desirability would include: French Guiana, Surinam Guyana or the balance of the Brazilian coast from Belem to Recife. Negotiations to obtain launching sites should be undertaken early in any full scale SPS scenario.

Conclusions

There is an appreciable saving which can be effected in fuel consumption by flight vehicles if large cargo ships are used launched from the equator, but transport of ground support equipment to the equator may negate such savings.

An equatorial launch site will provide schedule flexibility compared to a continental U.S. site.

Siting requirements for a South American country using a coastal launch would require approximately 200 square miles of land and an exclusion area in the adjacent sea.

VIII-C. ENERGY PAYBACK

William L. Gill
Systems Evaluation Off.

(An Evaluation of Resource-Requirements and Energy Payback of the SPS)

INTRODUCTION

Energy Analysis: One method of determining the feasibility of a proposed energy generation is to calculate the dollar cost of producing a kilowatt hour of electricity. Variables such as taxes, debt financing, rate of return, etc., have large effects on the cost of energy thus produced. Comparison of studies of energy generation systems may be difficult to make because of variations in these financial parameters from study to study.

Scientists and engineers engaged in finding new energy sources and conversion devices are more interested in the optimum use of energy. Minimizing depletion and insuring that energy sources are available. The medium of exchange for such determinations is energy, rather than dollars. Comparison of alternate systems borrows the financial parameter payback period and can develop an energy flow statement similar to the financial cash flow statement.

If all variables could be properly weighed in both financial and energy payback analyses, then comparable results should be obtained from both systems. However, such complete definitions may be difficult, if not impossible, to achieve in early design studies. Comparison of financial and energy studies can provide considerable insight into the best approaches in refining designs. In the case of the SPS, a nondepletable energy resource is being exploited, hence a net energy return insures conservation of depletable resources.

Resources: The construction and maintenance of a series of SPS's will require a considerable amount of raw materials. The questions which a design study must address are adequacy of resources and production capability.

Approach: To answer the above questions, a computer program has been developed to provide a flexible tool for the rapid evaluation of alternate SPS systems.

Program Concept: The program starts with an SPS on-station in synchronous orbit, together with the receiving rectennas on the ground. For this configuration, a series of matrices are input for each of the SPS subsystems (non-consumables). The rows of these matrices define individual components of the subsystem. The columns define the materials in the subsystem and the last three columns give the flight total mass, the ground total mass and the grand total mass in a particular subsystem component. The total amount of each material, the flight, ground and grand totals are then found by totaling the columns of these matrices. Next the vehicles, which are used to transport the SPS and personnel from the ground to geosynchronous orbit, are described. The nonconsumables making up each vehicle are arranged

in a matrix in which the columns of materials are the same as those for the SPS system. A second set of data for consumables per pound of payload are input for each vehicle. These data include the estimated lifetime of the vehicle. Using the selected cargo orbiting transfer vehicle data, the number of trips, the number of vehicles worn out and the amounts of consumables required to transfer the SPS from low-earth orbit to geosynchronous orbit are calculated. The mass of these materials are then added to the SPS mass to establish the payloads which must be transported from the earth's surface to LEO.

Similar calculations can be performed for assembly equipment, space manufacturing equipment, personnel and personnel support equipment. The transportation material expenditures for these equipment, depend on whether assembly and manufacture are perfomred in low-earth orbit or geosynchronous orbit.

The results of these calculations are arranged in two matrices. The first matrix is a summary of nonconsumables. In this matrix, the columns are the major systems of the SPS, the SPS construction system and the personnel support system, the total flight mass, the total ground mass and the grand total mass of the system. The rows are the various nonconsumable materials used in construction and the total mass in each of the columns. Where the materials making up a particular system were not completely known, the estimated mass of these materials were indicated in the MUD (Material Undertmined) row. The second matrix summarizes the masses and number of flights for each vehicle, the consumables used and the total consumables of each type.

The next section of the program looks at the payback period. Estimates of the energy required to produce various materials were made using a number of sources and will be discussed later in this section. The energy to produce a unit mass of a given material times the weight of the material when summed over all materials and divided by the power produced per year gives the payback period.

The last item to be considered is the availability of specific materials in the construction of the SPS. Two criteria are input and used for this evaluation; the annual demand for a given resource nationally and world-wide and the fraction of the total resource available, both nationally and world-wide. Both demand and resources are known only within fairly broad limits, and therefore, high medium and low values for the year 2000 are used as data input to the program. Critical resources or demands are then established by showing that the material exceeds some percentage of one of the levels of demand or resource. A typical run for the nominal column and cable design without the growth factor as given in last year's JSC study is shown in Appendix VIII-C.

Requirements: The inputs required to calculate the energy payback and the resources, demand loads consist of the following:

1. SPS design information consisting of:

a. The design data for the SPS.

b. The materials used to construct the various transport system vehicles.

c. The materials used to construct the space manufacture and assembly system.

d. The materials used to construct the space logistic bases and space stations.

e. The fuel consumption per flight of each of the various spacecraft.

2. Fabrication energy for the various materials used in the various systems listed below.

3. Resources data.

SPS Design Information

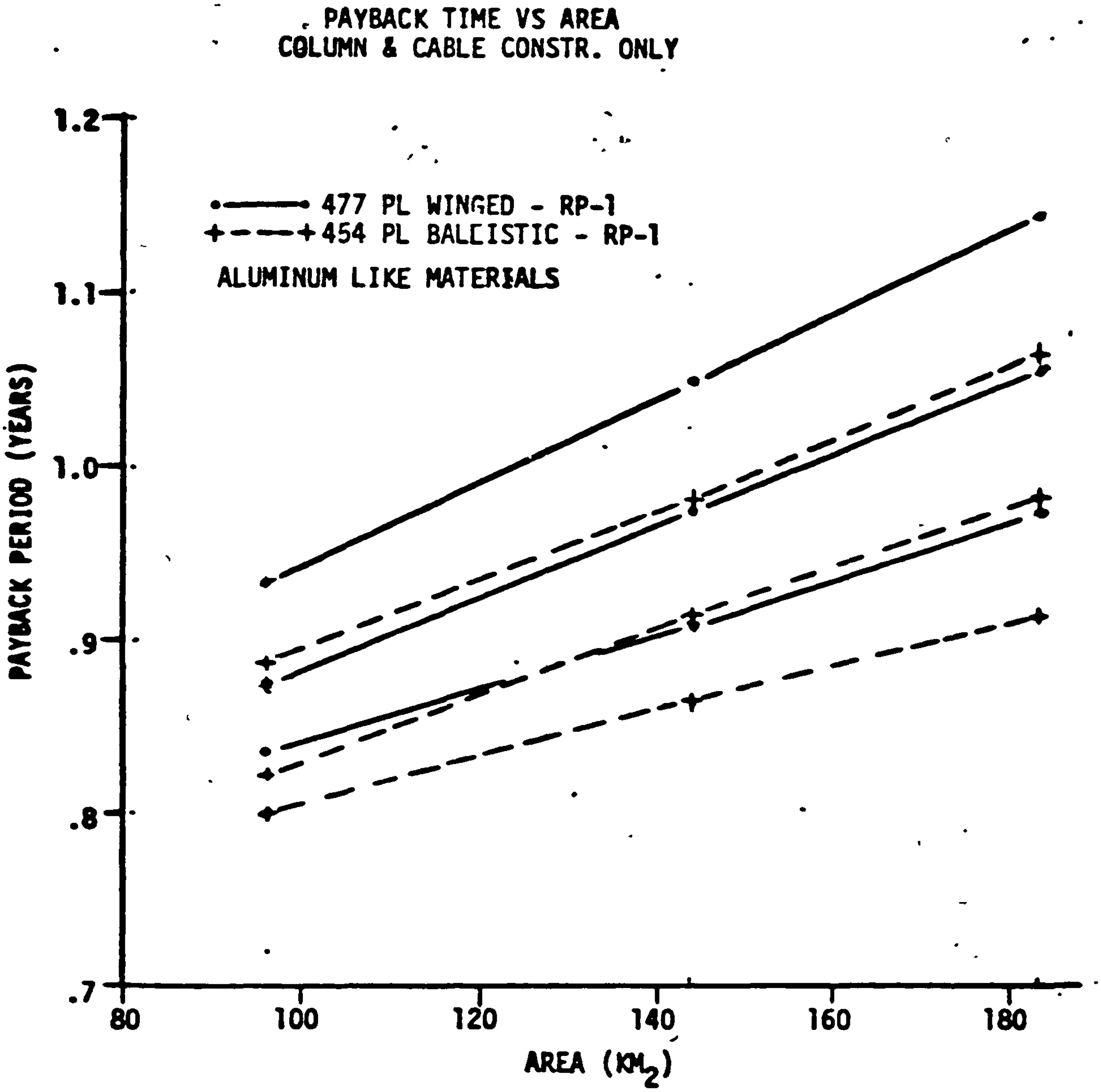
SPS: The SPS configuration was established in last year's Johnson Space Center's study. In this study there were nine possible satellite configurations varying in mass from 31,539 to 82,861 metric tons. Weight growth was estimated to add 50 percent to these weights resulting in satellite masses of 47,309 to 124,292 metric tons.

The initial JSC study provided three possible areas which depended upon overall system efficiency. The weight of each of these three area configurations varied depending upon the components making up the system. The transportation requirements vary with the total mass to be transported to orbit, and the overall effect on payback time can be seen in Figure VIII-C-1. The various fractions making up the payback period for the two extremes are shown at the bottom of Figure VIII-C-1.

Transport System Vehicles: Heavy-lift launch vehicles with payload capacities of from 195 to 900 metric tons to LEO, both winged and ballistic, were considered. Liquid hydrogen, propane and RP-1 were considered as fuels for these vehicles. Chemical propulsion using liquid hydrogen to GEO was used in this study. Ion propulsion or hybrid of ion and chemical propulsion data may be available at a later date. Personnel transfer vehicles have been defined and preliminary numbers of persons established. The energy required to construct these vehicles and to carry personnel to orbit are small and have been ignored in these first estimates.

Space Manufacture and Assembly System: It is still in such preliminary form as to be unavailable for estimates. Again, the energy expenditure is small and has been ignored.

Space Logistics and Bases and Space Stations: Same as above.



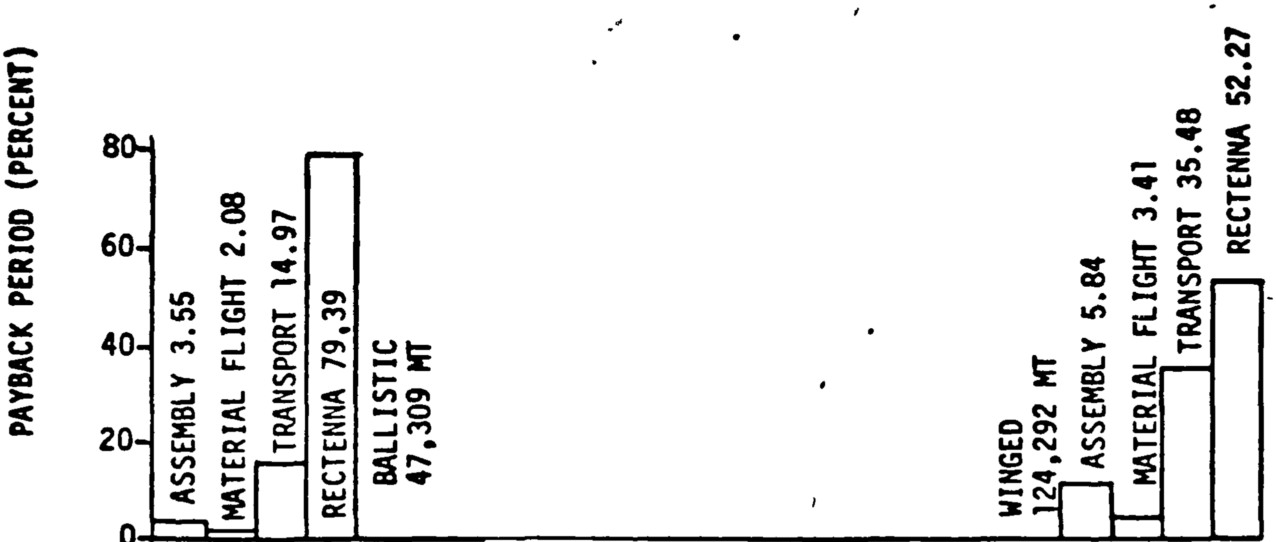


FIGURE VIII-C-1

Investigations of Fabrication Energy for Various Materials

Aluminum: Aluminum used in the rectenna is the largest single material in the SPS. The data contained in Tables VIII-C-1 through VIII-C-3 summarize the energy requirements for production of this material. The results are in good agreement with the values used in earlier reports.

Silicon Solar Cells are a key element in both cost and energy payback of an SPS. In the initial JSC study it was assumed that large-scale mass production would reduce the cost and energy requirements to produce solar cells. For this earlier study, a production energy of 24 KWH/Kg similar to that for aluminum was assumed possible by the time SPS was implemented. For this revision, a review of current production costs and ERDA research objectives were undertaken to assess the validity of this assumption. The fabrication energy for silicon cells cannot be easily separated from construction techniques, and impact the entire SPS design. A complete discussion of solar cell fabrication energy is given in the results section of this report.

Liquid Oxygen is used in all transport systems proposed for SPS and liquification of air is the most efficient method of producing this product. The preparation of spacecraft for launch require large quantities of liquid nitrogen. Based upon consumption records at Cape Kennedy, the ratio of liquid oxygen used in flight to oxygen produced, losses were estimated at 50 percent. The ratio of nitrogen used to oxygen used was estimated at 1.25. The ratio of liquid nitrogen to liquid oxygen produced is about three to one; hence, an excess of liquid nitrogen exists. As shown in Figure VIII-C-2, this excess could be sold as a by-product, or the excess might be used to pre-cool incoming air, thus increasing the efficiency of the overall system. Oxygen might also be obtained as a by-product of the electrolysis of water to produce oxygen. Liquification would require .858 kw hour/kg under these conditions or 1.761 kw hour/kg to the spacecraft if launch site losses are considered. Conservation measures may reduce the historical launch site losses. The energy payback period for liquid oxygen is a fraction of a percent of the total SPS payback. A wide variation in its production energy will not significantly change the SPS payback period.

Liquid Hydrogen: As presently configured, the SPS transport system uses hydrogen for the upper stage of the HLLV; the chemical OTV and personnel transfer vehicles. Six production method using natural gas, oil, coal, to nuclear and solar energy could be available. Of the available methods, steam reformation of natural gas is the most energy efficient method of producing hydrogen, followed by partial oxidation of oil and coal gasification, nuclear electric, nuclear thermal. Steam reformation of gas, oxidation of oil and solar thermal electric are not expected to be major contributors hydrogen supply. Coal gasification is about twice as efficient as electric means of producing hydrogen. Hence, any estimate of hydrogen payback time is uncertain by a factor of 2. Table VIII-C-4 shows the estimated year 2000

ALUMINUM ENERGY REQUIREMENTS (1)

PROJECTED ENERGY TO PRODUCE

OPERATION	THERMAL ENERGY (BTU/MT)	THERMAL ELECT. EQUIVALENT (KWH/MT)	ELECTRICAL (KWH/MT)	TOTAL ELECT. EQUIVALENT (KWH/MT)
MINING & ORE PURIFICATION	28.6×10^6	2860	440	3300
TRANSPORT (1000 MI 200 TON MI/GAL)	6.7×10^5	675	0	675
METAL PRODUCTION	26.4×10^6	2640	14332.5	16972.5
MILL PROCESS	28.6×10^6	2860	1660	4520

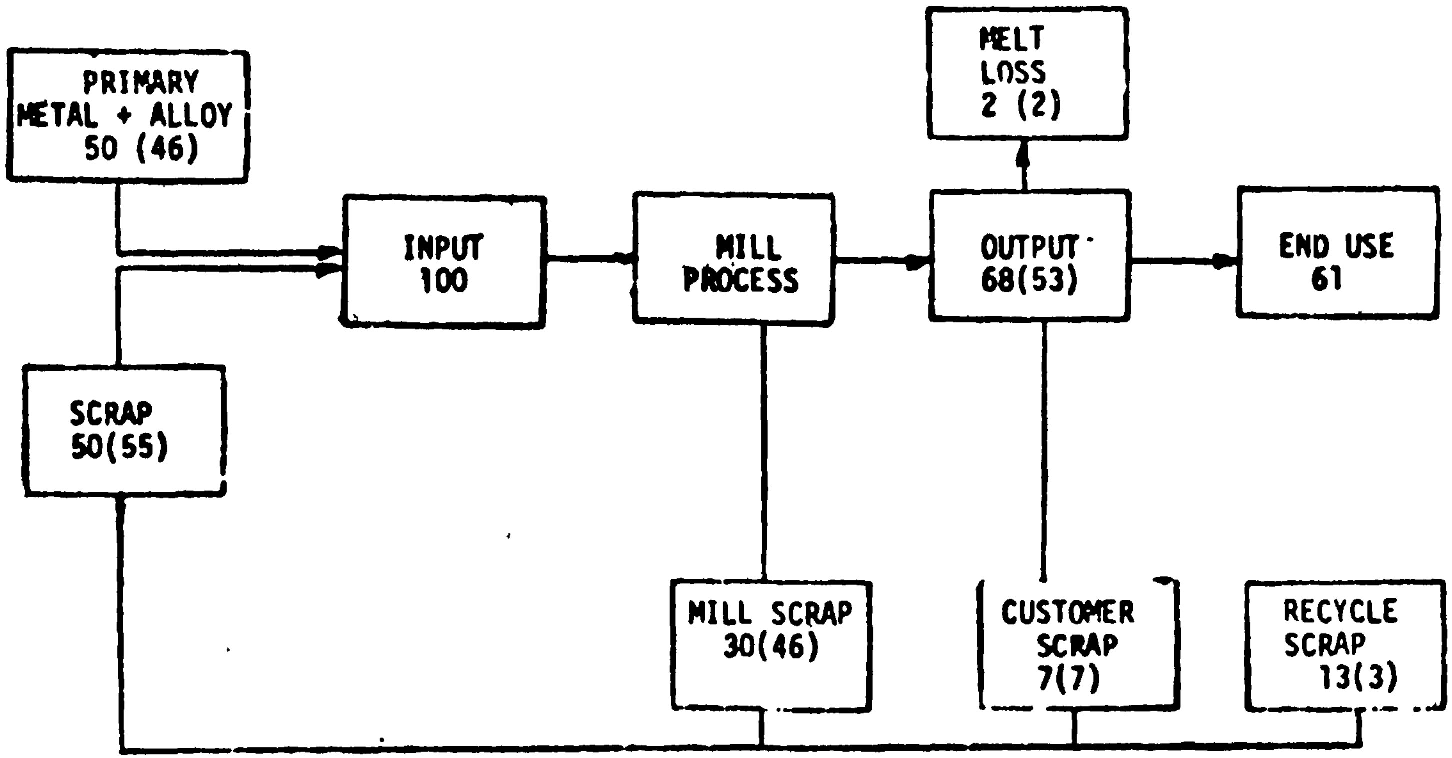
REF: 1. ALLEN S. RUSSELL ENERGY CONSERVATION IN PRIMARY METALS PROCESSING. PP 123,138 ENERGY DELTA SUPPLY VS DEMAND, VOL. 35 SCIENCE & TECHNOLOGY, AAS PUBLICATION, GEORGE W. MORGENTHALER, AARON N. SILVER,EDITORS, 1975

2. ARTHUR E. UHL, FUEL ENERGY SYSTEMS CONVERSIONS & TRANSPORT ENERGIES, PP 578-587, 9th INTERSOCIETY ENERGY CONFERENCE, 1974 PROCEEDINGS, ASME

TABLE VIII-C-1

ALUMINUM ENERGY REQUIREMENTS (2)

PRIME METAL PRODUCTION ENERGY/MT = MINING ENERGY + TRANSPORT ENERGY + METAL PRODUCTION = 3300 + 675 + 16972.5 = 20947.5 KWH/MT



REF: IBID (1) (1)
PAREN NUMBER: AS PUBLISHED IN REFERENCE
NON PAREN NUMBER: AUTHORS ESTIMATE FOR 2000 PERIOD

TABLE VIII-C-2

ALUMINUM ENERGY REQUIREMENTS (3)

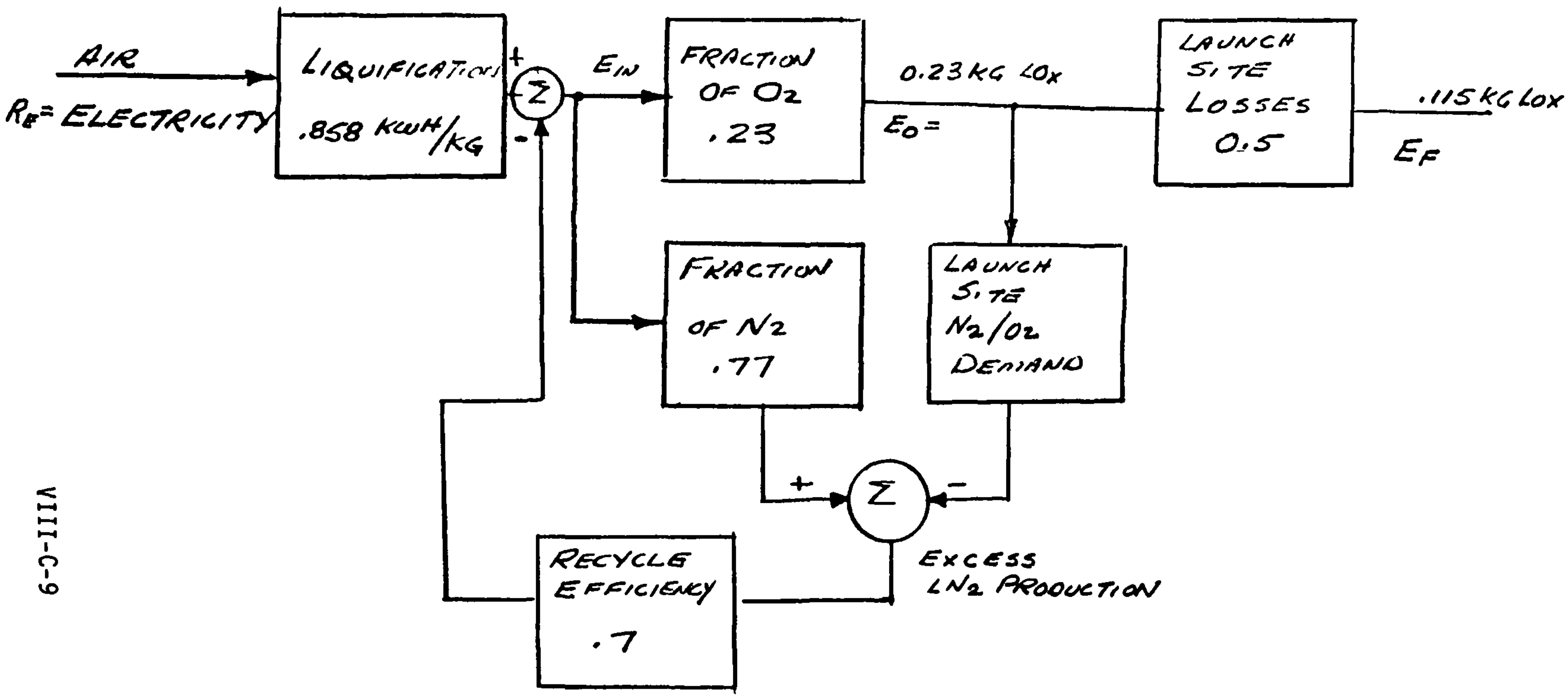
ENERGY PER MT OF FINISHED PRODUCT $= 50 \begin{pmatrix}\text{PRIME METAL}\\\text{PRODUCTION}\end{pmatrix} + 100 \begin{pmatrix}\text{MILL}\\\text{PROCESS}\end{pmatrix} \div \begin{pmatrix}\text{END}\\\text{USE}\end{pmatrix}$

$= 50\ (20947.5) + 100\ (4520) \div 61$

$= 24579.9$ KWH/MT $= 24.57$ KWH/KG

PREVIOUS USED VALUE 24.0 KWH/KG

TABLE VIII-C-3



E_{IN} = .7475 R_E = .641 KWH/Kg

E_O = 2.786 KWH/Kg LOx PRODUCED

E_F = 5.574 KWH/Kg LOx TO SPACE CRAFT

LIQUID OXYGEN - LIQUID NITROGEN PRODUCTION

FIGURE VIII-C-2

HYDROGEN PRODUCTION

MANUFACTURING BREAKDOWN

PRODUCTION METHOD	ENERGY REQ. THERMAL (KWHR/KG)	ESTIMATED YR 2000 PRODUCTION PERCENTAGE	WEIGHTED PRODUCTION ENERGY (KW/KG) THERM	ELEC OUTPUT EQUIV KW/KG
STEAM REFORMING OF NATURAL GAS	53.059	5	2.653	
PARTIAL OXIDATION OF OIL	61.47	5	3.0735	1.024
COAL GASSIFICATION	72.47	45	32.62	10.873
NUCLEAR ELECTRIC	120.35	40	48.41	48.41
NUCLEAR THERMAL	120.35			
SOLAR THERMAL ELECTRIC	198.65	5	9.93	9.93
EST YR. 2000 PRODUCTION ENERGY			96.41	71.11
LIQUIFICATION ENERGY REF. 2			12.52	12.52
SUM			108.93	83.63
LAUNCH SITE HANDLING EFF. EST. SHUTTLE ~ 97 APOLLO ~70			.9	
TOTAL ENERGY			121.0	92.91
UNCERTAINTIES IN GROUND TRANSPORT AND STORAGE EFF. ~ .8			150.4	116.13

REFERENCE (1): JAMES H. KELLEY, STUDY MANAGER: EUGENE A LAUMANN, DEPUTY MANAGER; HYDROGEN TOMORROW - DEMANDS AND TECHNOLOGY REQUIREMENTS - REPORT OF THE NASA ENERGY SYSTEMS TECHNOLOGY STUDY, JPL, DEC. 1975.

REFERENCE (2): W. R. PARRISH, ETAL.; J. HORD, EDITOR; SELECTED TOPICS ON HYDROGEN FUEL, NBSIR - 75-803, CRYOGENICS DIVISION INSTITUTE OF BASIC STANDARDS, NATIONAL BUREAU OF STANDARDS, JANUARY 1975.

TABLE VIII-C-4

production energy to hydrogen based upon a weighted production percentage. In Figure VIII-C-3, the overall production scheme for liquid hydrogen is shown and in Table VIII-C-5 an estimate of storage and transportation losses have been applied. Some estimates of storage efficiency and boil-off losses are given in Table VIII-C-5. Liquid hydrogen has been estimated to require .16 year for energy payback. If coal gasification were used exclusively, then a reduction by nearly a factor of two might be possible; however, there would be some increase in energy requirement under these conditions to compensate for coal and water transport.

Concrete: The JSC study of last year did not consider the structural concrete required for the rectenna. The energy of production was obtained from "Energy Conservation in the Cement Industry," Hoke M. Garrett and James A. Murray as published in "Energy Delta Supply vs. Demand," Vol. 35, Science and Technology, A Supplement to Advances in Astronautical Sciences" edited by George W. Morgenthall, Arron N. Silver. Proceedings of Energy Symposium of the American Association for the Advancement of Science, February 25-27, 1974, San Francisco, California, AAS Publications Office, P. Box 746, Tarzana, California 93156. Although concrete ranks second by weight of materials used in the SPS, the energy required to produce it is low (.77 kw/kg). It is estimated that concrete requires less than .02 years payback time. For the current payback calculations, the cost of transportation to the rectenna site, mixing, preparation of forms and pouring have been neglected pending more definitive designs. Requirements for reinforcing steel bars have also been neglected.

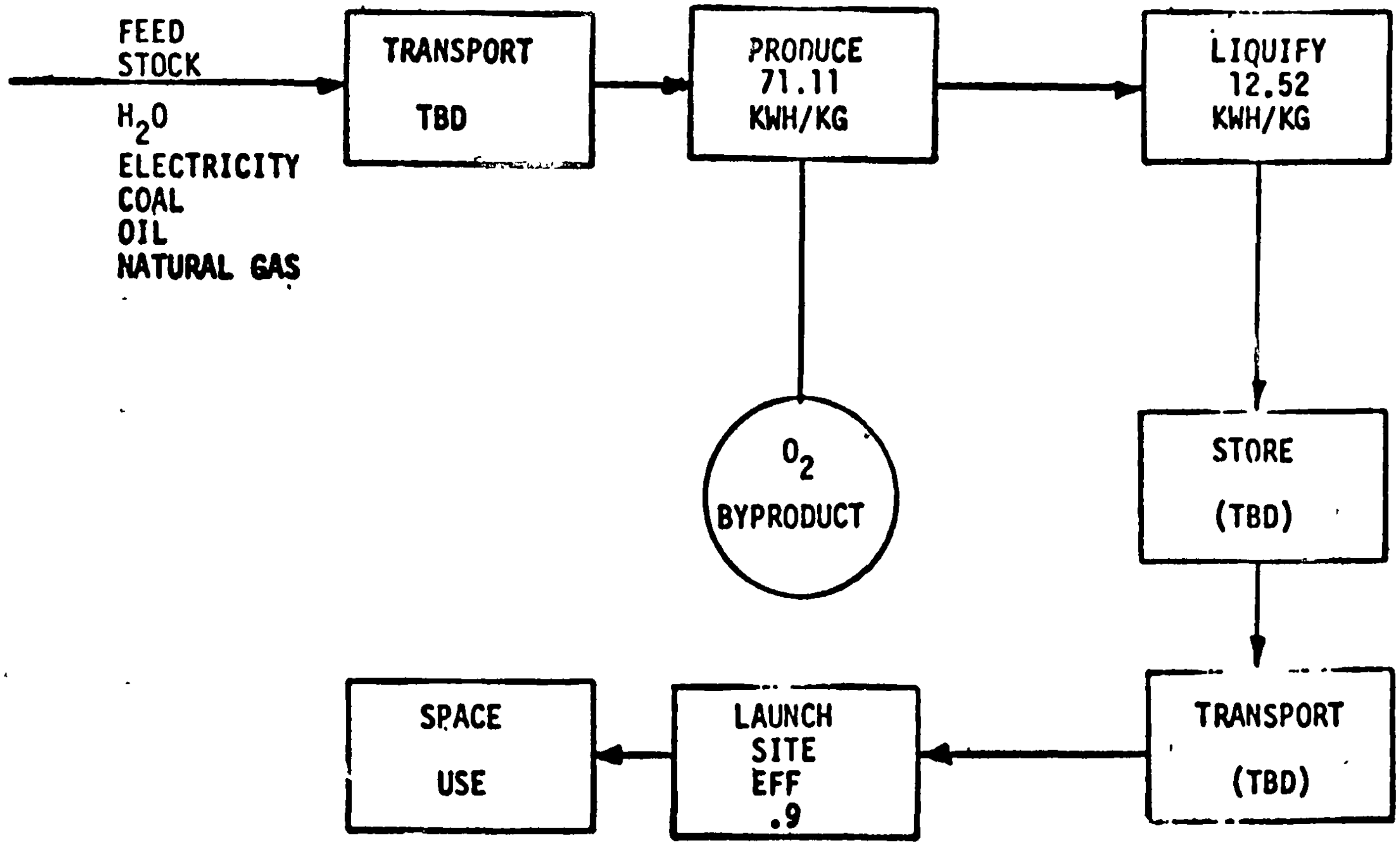
Revisions to Last Year's Payback Times and Resource Requirements

This assessment requires that several variables be considered simultaneously. First the SPS can be considered to be constructed of two different kinds of materials; those in which the amounts of material depend upon the overall system efficiency and those which are independent of system efficiency. In each of these kinds of material the energy to produce, transport and maintain them must be considered in establishing payback times. In the case of solar collection, the units are best considered in terms of intensity or per unit area. The following equation summarizes the relationship between payback time and the various material making up the solar power system.

$$Y_{c\ or\ m} = \frac{\sum_{\ell=1}^{p} \sum_{i=1}^{n} W_{i\ell} (e_i + t_j + v_j + a_{kj}) + \frac{D}{\phi \eta_t} \sum_{f=1}^{q} \sum_{m=1}^{r} (\sigma_m (e_m + t_j + v_j) + a_p)}{P(8760 - \sum_{c=1}^{s} O_c)R}$$

Y	=PAYBACK TIME IN YEARS OF SATELLITE CONSTRUCTION (c) OR MAINTENANCE (m)	YEAR
$W_{i\ell}$	=MASS OF MATERIAL i IN SUBSYSTEM ℓ., SUBSYSTEM ℓ IS INDEPENDENT OF EFFICIENCY OF OVERALL SPS	MT
$e_{i\ or\ m}$	=ENERGY PAYBACK OF MATERIAL i or m PER UNIT MASS OF MATERIAL i or m	(YEARS/MT)
t_j	=ENERGY PAYBACK OF PROPELLANT IN TRANSPORT SYSTEM j PER UNIT MASS TRANSPORTED USING TRANSPORT SYSTEM j	(YEARS/MT)
v_j	=ENERGY PAYBACK OF WORN VEHICLES IN TRANSPORT SYSTEM, PER UNIT MASS TRANSPORTED USING TRANSPORT SYSTEM j	(YEARS/MT)
$\frac{D}{\phi}$	=DELIVERED POWER OF SPS TO GRID/SOLAR INTENSITY	M^2
a_{kj}	=ENERGY PAYBACK OF ASSEMBLY OR MAINTENANCE INCLUDING PERSONNEL BURDEN OF ASSEMBLY SYSTEM k USING TRANSPORT SYSTEM j PER UNIT MASS TRANSPORTER	YEARS
a_{pj}	=ENERGY PAYBACK OF ASSEMBLY OR MAINTENANCE PER UNIT AREA ASSEMBLED USING TRANSPORT SYSTEM j	YEAR
η_t	=OVERALL SPS SYSTEM EFFICIENCY = $\prod_{a=1}^{b} \eta_a$ WHERE η_a IS THE EFFICIENCY OF SUBSYSTEM a	
σ_m	=MASS PER UNIT AREA OF MATERIAL m	$\frac{MT}{m^2}$
O_c	=OUTAGE TIME FOR REASON c PER YEAR	HOUR
R	=DECAY FACTOR FOR SOLAR CELL OUTPUT	
$\sum_{f=1}^{q}$	=INDICATES SUMMATION OVER ENERGY DEPENDENT SUBSYSTEMS	

HYDROGEN PRODUCTION



$$\text{TOTAL ENERGY/KG} = \frac{71.11 + 12.52}{.9} = 92.91 \ \frac{\text{KWH}}{\text{KG}}$$

FIGURE VIII-C-3

HYDROGEN PRODUCTION

STORAGE DATA

STORAGE EFFICIENCY OF LIQUID HYDROGEN CONTAINERS[1]

CAPACITY (GAL.)	USE	BOIL-OFF (%/DAY)
900,000	Stationary	.03
500,000	Stationary	.05
28,000	Rail Car Delivery	.3
13,000	Truck Delivery	.5
260	Mobile	1.0
40	Mobile	2.0

ORTHO TO PARA CONVERSION OF LIQUID HYDROGEN[2]
609 BTU/# H_2 CONVERTED
CATALYST MAY BRING CONVERSION TO ≈87% COMPLETION

BOIL-OFF LOSSES FOR CONVERSION

PARA CONCENTRATION	BOIL-OFF LOSS PERCENT/DAY
98	0.019
95	0.119
90	0.48
80	1.9
70	4.3
60	7.6
50	11.9
40	17.2
25	26.8

Reference (1): Edward H. Dickson, John W. Ryan, Marilyn Hl Shulyan - They Nitrogen Economy - A Preliminary Technology Assessment, SRI Draft Report, SRI Project EGU-2838, July 1975.

Reference (2): Ch. 51, ASHRAE Handbook and Project Directory 1974 Applications

TABLE VIII-C-5

Aluminum: Last year's energy resource analysis indicated that aluminum used in the rectenna was the dominant energy consuming material in the SPS. The amount of aluminum used in the design of the rectenna has been reduced by substituting structural iron in the rectenna design. The revised weights, fabrication energies and payback times for the rectenna of the JSC report and the revised antenna are shown in Table VIII-C-6 below.

TABLE VIII-C-6

5 GW Rectenna
Masses and Payback Time

Item	Previous Rectenna Mass Tonne.	Previous Rectenna Payback Energy KWH	Revised Rectenna Mass Tonne.	Revised Rectenna Payback Energy KWH
Structural				
Aluminum*	$.56 \times 10^{6}$	1.37×10^{10}	$.150 \times 10^{6}$	$.37 \times 10^{10}$
Steel	-----	------	1.45×10^{6}	$.20 \times 10^{10}$
Concrete*	1.36×10^{6}	$.19 \times 10^{10}$	1.43×10^{6}	$.16 \times 10^{10}$
Land Preparation*	-----	$.4 \times 10^{10}$	------	$.4 \times 10^{10}$
Electronics				
Dipoles	-----		$.150 \times 10^{6}$	$.37 \times 10^{10}$
		1.98×10^{10}		1.53×10^{10}
Payback Time+		.492		.381

*Page IV D-1-b-1. Vol. II. Detailed Report Initial Technical Evaluation and Economic Evaluation of Space Solar Power Concepts, August 31, 1976, NASA Lyndon B. Johnson Space Center, Houston, Texas.

+4.025×10^{10} kwh/year per Rectenna

ERDA PROGRAM GOALS

	CALENDER YEAR					
	1976	1978	1980	1982	1984	1986
S_i MATERIAL IN FINAL PRODUCT %	27	30	38	78	87	91
TOTAL PROCESS VALUE ADDED %	84	71	75	87	73	64
WATTS/KG OF SILICON MATERIAL	32	47	62	162	187	203
CELL EFFICIENCY (AM1)	11	11.5	12	12.5	13	13.5
CELL THICKNESS (MILS)	15	12	12	10	10	10

TABLE VIII-C-7

Silicon: The energy consumption for silicon solar cells was made low in last year's report, but achievement of this goal will require a considerable research effort. In the research being carried out by ERDA, there are three variables - energy required to produce a unit mass of material, conversion efficiency and cell thickness or weight per unit area. Conversion efficiency varies between ground and space. Figure VIII-C-4 shows the steps which must be taken to compare the payback values for the SPS used in the initial JSC report and those which would result if the ERDA research meets its goals. Table VIII-C-7 summarizes the objectives of the ERDA low-cost silicon solar array project.

In "Potential Improvements in the Efficiency and Cost of Solar Cells," Proceedings, IEEE 10th Photovoltaic Conference, November 1973, page 8, and "Cost Goals for Silicon Solar Arrays for Large Scale Terrestrial Applications," 9th Photovoltaic Specialist Conference, IEEE, May 2-4, 1972, page 346, M. Wolf estimated the fabrication energy for silicon solar cells. Seymour Baron in "Energy Cycles - Their Cost Interrelationship for Power Generation," Mechanical Engineering, June 1976, page 22-30, estimated the payback period for a terrestrial solar voltaic power plant as 48 years. Martin G. Gandel and Paul A. Dillard, in "Assessment of Large Scale Photovoltaic Materials Production," LMSC HREC-D496940, July 16, 1976, trace, in detail, the steps to produce solar cells and itemize both the materials and energies required in each step. Figure VIII-C-4 is a highly simplified flow diagram of the energy expenditure for solar cells, and demonstrates the considerable improvement which will result from the ERDA program.

The efficiency of solar cells (13.5%) being developed by ERDA ground solar cell system are lower (4.2 to 8.0%) than those postulated in last year's JSC report. Assuming no other major solar cell development program, so that ERDA cells were used in space, what would be the effect on the SPS payback period? Last year's JSC report established a set of high/low and nominal solar cell efficiencies, and a corresponding set of overall system efficiencies. From these data, the set of efficiencies corresponding to all the SPS system except the solar cells can be established. The efficiency of a solar cell operating in space is different than one operating in a ground-based system. In Figure VIII-C-5, the effect of substituting the ERDA development solar cell for the cell described in last year's report is shown. The result lowers the overall efficiency of the SPS to the range of 2.72 to 4.6 percent.

Last year's JSC report added 50 percent to the calculated mass of the satellite for growth. The reduction in solar cell efficiency described in the preceding paragraph will require that the area of the satellite be increased by about 50 percent. Table VIII-C-8 compares the JSC area with growth to the areas required if ERDA cells are used. Thus, the use of ERDA ground-based solar cells in the SPS system from an area standpoint would appear to fall within the growth envelope postulated in last year's JSC report.

ENERGY EXPENDITURE FOR $S_i^?$ SOLAR CELLS

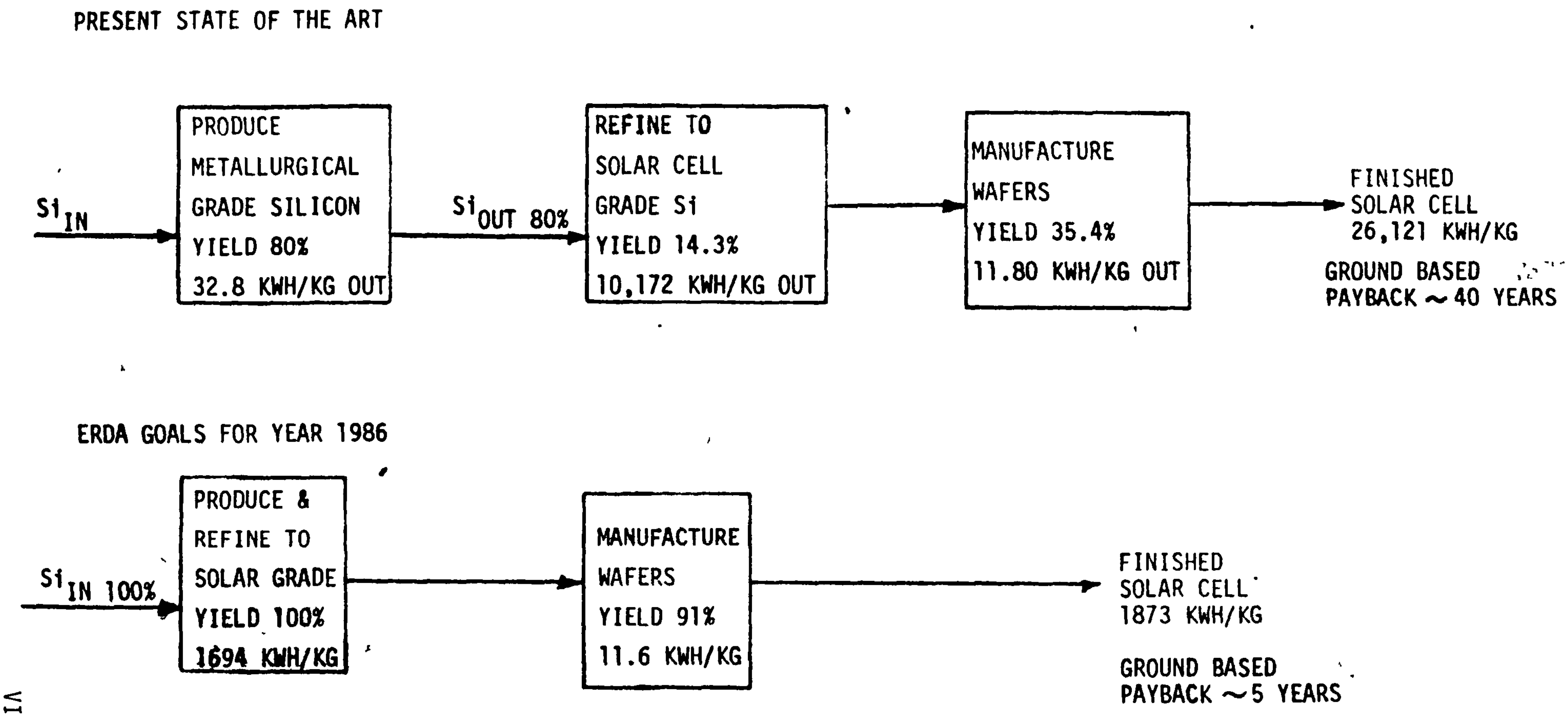


FIGURE VIII-C-4

AREA EFFECTS

GREEN BOOK AREA	GREEN BOOK WITH 50% GROWTH	WITH ERDA CELLS	ERDA/1.5 X DESIGN AREA
REFERENCE - 143.4	215.0	193.7	.90
MINIMUM - 96.1	144.2	147.2	1.02
MAXIMUM - 182.9	274.4	249.1	.907

TABLE VIII-C-8

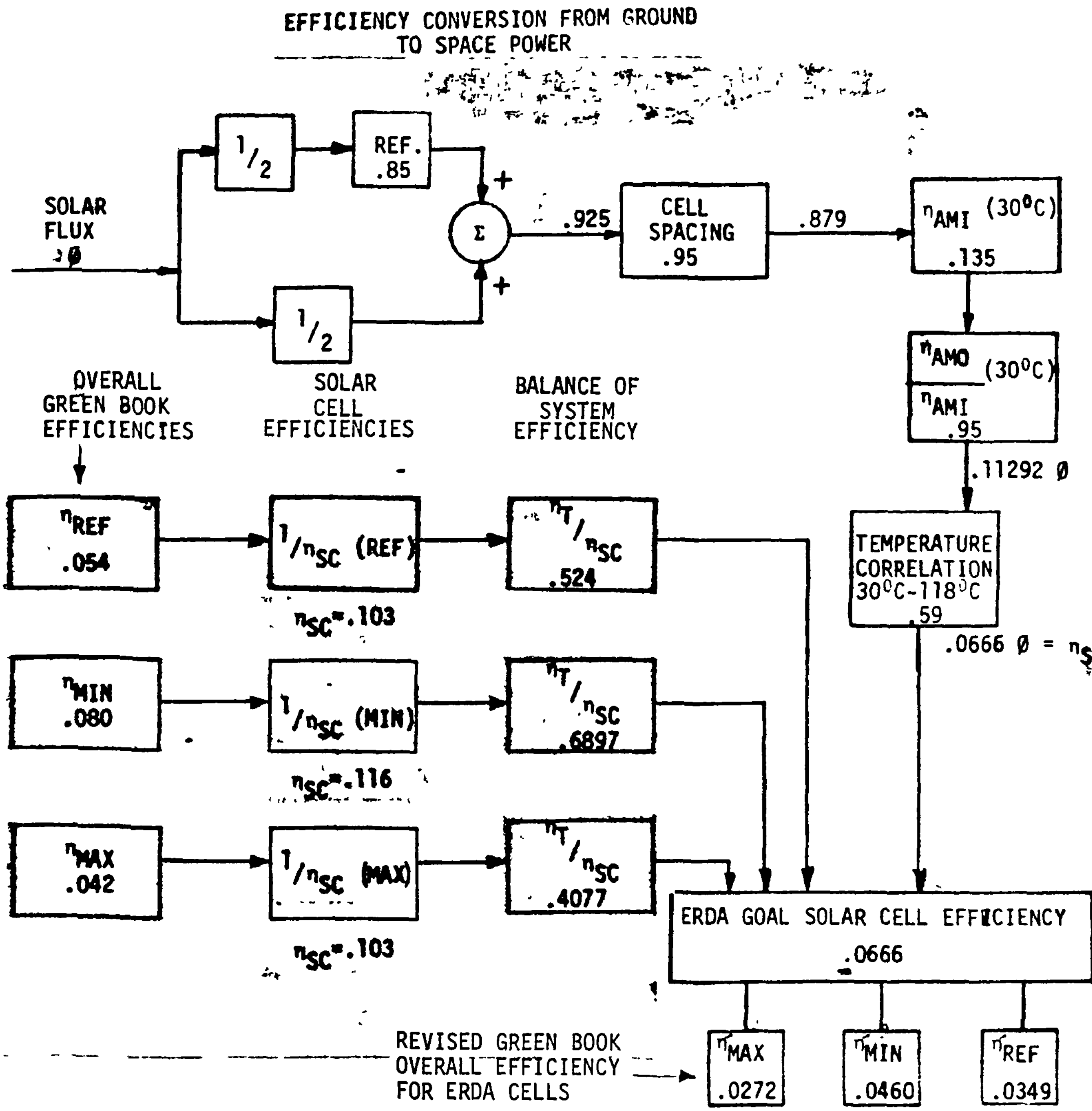


FIGURE VIII-C-5

Effects of Varying Cell Thickness

In last year's JSC report, the solar cell thickness had a nominal value at 4 mils and weighed 0.4 kg/m^2. The high and low area densities ranged from 0.31 kg/m^2 to 0.46 kg/m^2. The ERDA goals would develop a cell 10 mils thick.

In Figure VIII-C-6 and VIII-C-7, the effects of various combinations of solar cell efficiencies and masses on SPS payback times are shown. Irrespective of the type of solar cell used, the microwave transmission system will require up to 0.75 of year to payback, and is independent of solar cell efficiency (non-energy dependent component). The solar cell array (energy dependent component) postulated in last year's report and the transportation system used to place it on-station when added to the non-energy dependent component raises the payback period from .8 to 1.2 years and ranges in area from 96.1 to 143.4 km^2. If solar cells were obtained with the range of thickness specified in last years report, the total payback period would range from 1.1 years to 1.6 years and the corresponding areas would be between 193.7 to 249.1 km^2. If cells of the thickness being developed by ERDA are used, the payback can be as high as 2.2 years.

These results show that the research in solar cells is rapidly reducing their energy costs. The payback period will drop from 40 years to 2 years if all ERDA goals are met. If research is undertaken, the goals of a 16 percent (30°C) efficient solar cell with an operating efficiency of 10.3 percent appear reasonable in the time period of the SPS. The second goal of 4 mil versus the ERDA 10 mil thickness would also appear achievable in the time periods of SPS construction. The solar cell fabrication energy can, however, rapidly increase the payback time, and research development efforts in this area with the objective of satisfying SPS requirements should receive high priority.

FIGURE VIII-C-6

EFFECT ON GREEN BOOK DESIGN
OF ERDA PAYBACK ENERGY,
EFFICIENCY AND THICKNESS

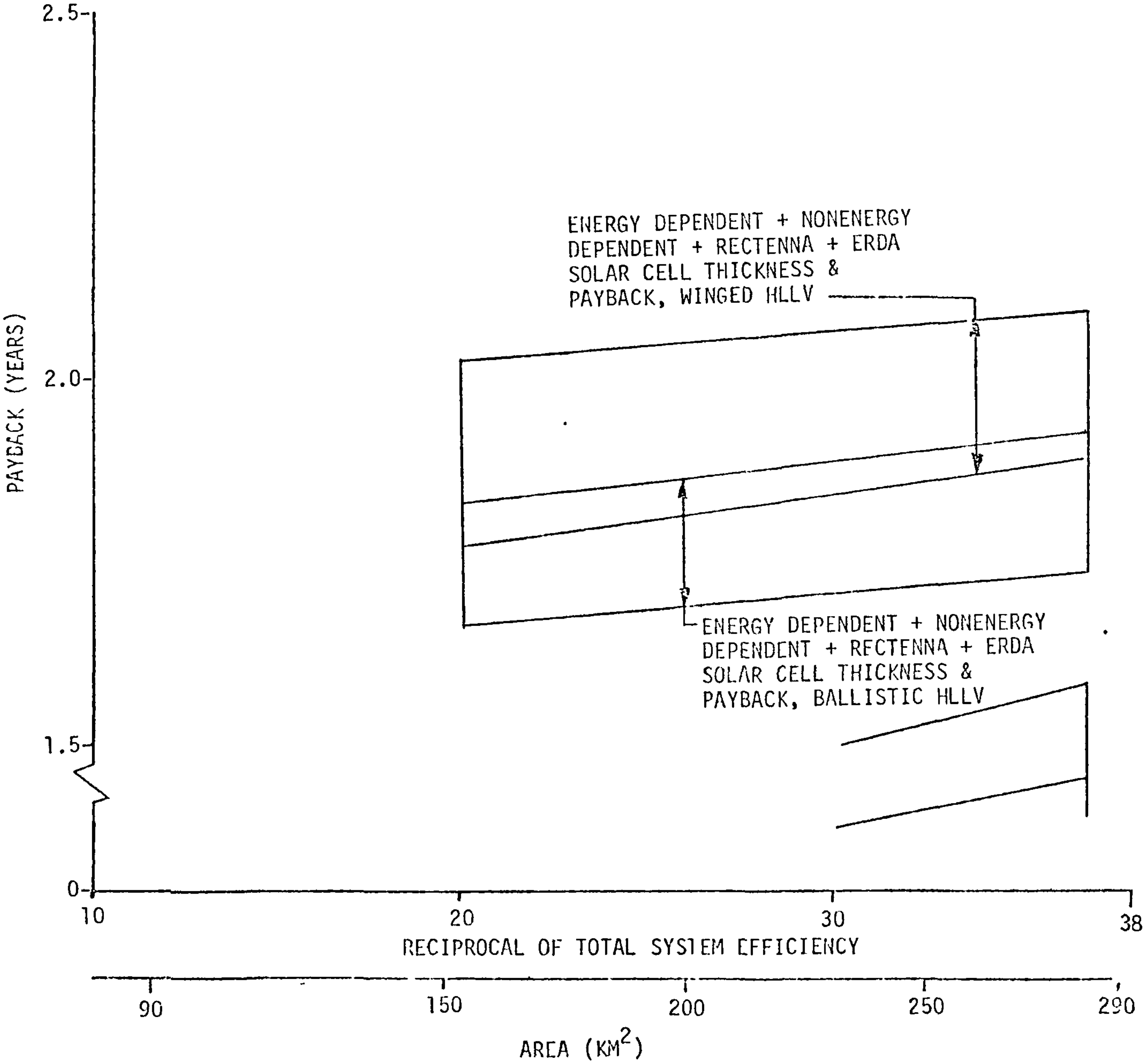
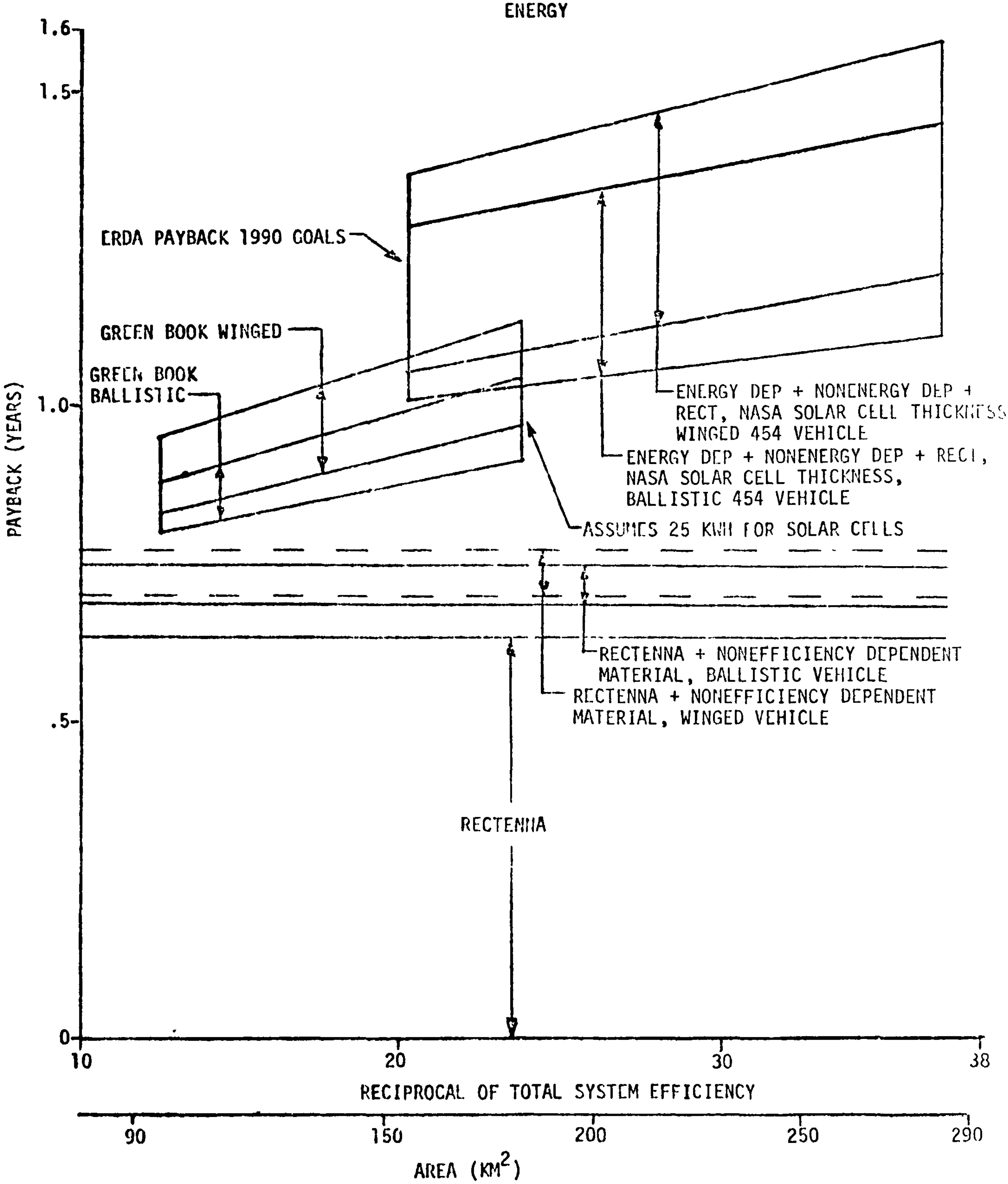


FIGURE VIII-C-7

ENERGY PAYBACK COMPARISON OF GREEN BOOK DESIGN AND ERDA EFFICIENCY AND PAYBACK ENERGY



VIII-D. SYSTEMS ENERGY BALANCE

William L. Gill
Systems Evaluation Off.

BACKGROUND

Last year's report determined the construction energy and payback time for the SPS. Construction energy and payback time were considered equivalent to the capital investment for the plant, and comparison of SPS values to other power generating systems could provide an indication of the economic viability of the SPS based upon initial costs.

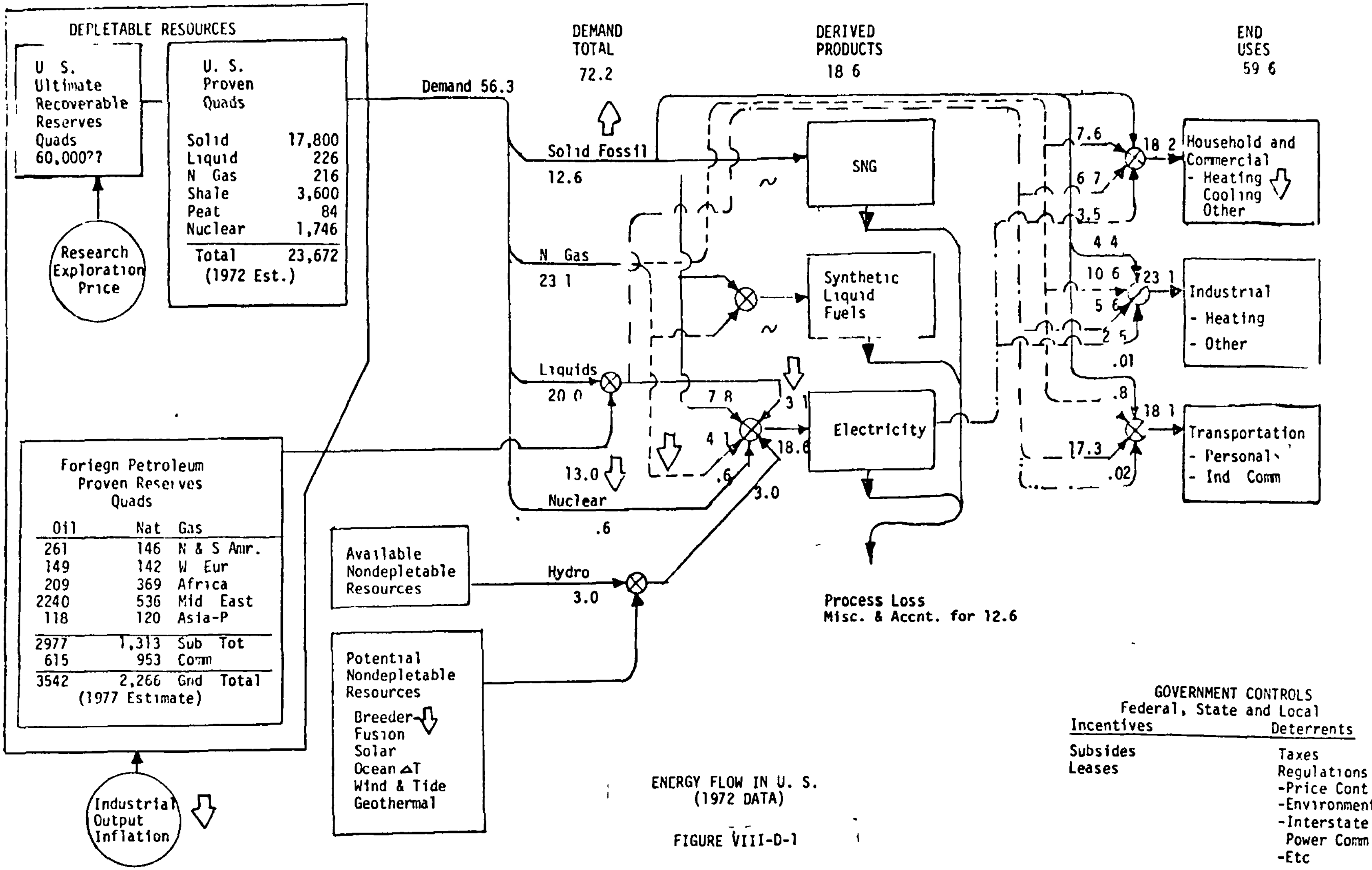
In this year's report, the lifetime energy operating budget is examined. Conventional systems use depletable resources while generating power, while the SPS does not. When considered over the lifetime of power generation, it will be shown that the SPS can provide for more efficient use of depletable fuel resources and can substitute in part for such resources.

In the initial part of this section, the energy flow through the U. S. economy is traced. The type of energy resources used, the reserves of these resources, and some estimates of their lifetimes and rates of extraction are made. Some of the effects of these supply-demand relationships on a conventional utility system are traced. Next lifetime energy costs are examined. Energy use by SPS, conventional systems and ground-based solar power systems are made.

ENERGY AVAILABILITY

Flow In U. S. Economy

Figure VIII-D-1 shows the energy flow through the U. S. economy. Starting at the upper left, the total U. S. proven reserves which are available at current market prices of about $12/bbl of oil equivalent, are some 20,000 quad, and based upon the demand rate in 1972, should last some 280 years. Based upon President Carter's projected growth rate of 2 percent per year, would give an average demand to 1985 of about 78 quad, which means that proven reserves would last 262 years at that rate. When the individual demands for natural gas and petroleum are compared to their proven reserves, natural gas is available from U. S. sources for less than 10 years, depending upon its variation with time, and liquid petroleum is available less than 7 years, from proven U. S. reserves. As pointed out in "Resources in America's Future, Patterns of Requirements and Availabilities - 1960-2000," by Hans H. Landsberg, Leonard L. Fischman, and Joseph L. Fisher, Resources for the Future, Inc., by John Hopkins Press, 1963, the ratio of U. S. crude production to proven resources has varied narrowly between 11.5 and 13.6 for the period 1944 to 1960. By 1972, this number had dropped to 10.5. The amount of imported oil has steadly risen, hence it is more meaningful at this point to compare demand to proven reserves, which is now about 7. The 1944-1960 ratio of about 12 to 1 was experienced in a "laisser faire" type economy with little or no regulation. It appeared to represent about the average lifetime of an oil well.



ENERGY FLOW IN U. S.
(1972 DATA)

FIGURE VIII-D-1

New wells were drilled as required to satisfy demand. From 1960 to the present, the amount of foreign crude steadily increased to where it currently satisfies about 40 percent of demand, and it thus will extend our current proven reserves to about 11 years. The comparison with coal is striking; based upon current coal demand, there is sufficient coal to last 1400 years.

The distribution of these demands are next traced through the economy. Simplistically at present, there is only one derived product from raw energy sources, electricity; but two others are indicated: synthetic natural gas and synthetic liquid fuel. The principal feed stock for these materials is coal, with conversion energy being supplied by either coal or electricity. Considerable conservation of depletable fossil fuel resources can be affected if nondepletable resources can be developed, or if nuclear fuels can be used. From the data in Figure VIII-D-1, it can be seen that light water reactor fuel reserves could supply all the electrical demand for less than 20 years.

Of the nondepletable resources, only hydroelectric is currently available. This resource is essentially fully developed, and no new contribution can be expected.

Of the nondepletable resources, the breeder reactor is closest to operation and is the energy source being pursued in Europe. The arrow pointed downward adjacent to this source indicates current government policy to not develop, based upon nuclear weapons and environmental considerations. The remaining nondepletable resources are fusion, solar and ocean delta-T. Fusion is actively being studied, but initial power production may be as much as 20 years away. Ocean delta-T requires a large energy investment and may produce no net energy. Wind and tide and ground-based solar all require some storage system in order to match electrical demand, with results in a marked reduction in net energy generated. The use in connection with synthetic fuel production may overcome this difficulty. Space solar power can give good direct baseline electrical service and appears to be technically feasible.

At present, President Carter's energy policy is placing emphasis on conservation. As shown in Figure VIII-D-1, the use of natural gas and liquid fuels for electrical generation will be replaced by solid fuels. The current goal is to increase solid fuel consumption by about 60 percent by 1985. This goal, when achieved, would effectively decrease natural gas demands by about 18 percent and liquid fuels by 9 percent.

In household and commercial end use, the use of solar energy and insulation under a government incentive plan would further reduce the total demand for natural gas and liquid petroleum. Electrical heating using space solar power as an energy source could be added as a future option. Good estimates of the total potential saving are not available, but as can be seen in Figure VIII-D-1, the total of natural gas and liquid fuels would not exceed 14 quad in 1972 figures or about 16.5 quad in 1985.

In the industrial consumption area, the government seeks to reduce the amount of natural gas used for industrial heating; roughly estimated as about 4 quad. The balance is used in oil fields, pipeline transmission, chemical and fertilizers, refineries and carbon black manufacture; hence, are probably not reducable.

In the transportation area, gasoline consumption is the principal target for conversion. The average consumption is targeted at 6.75 million barrels per day through 1985. A strong deterrent of taxes will be used to achieve this goal. This would roughly correspond to 1972 level of gasoline production or about 13 quads. Savings would be about 4 quad per year. In summary, the following savings are estimated to result from the President's proposed policy.

TABLE VIII-D-1 SAVINGS-QUADS/YEAR

Usage	Natural Gas	Liquid Petroleum
Electric Gen.	4.1	3.1
Household and Commercial	5.0	5.0
Transportation	---	4.0
Totals.	9.0	12.1

Oil imports are to average around 15 quad per year from 77 to 85.

Estimated domestic demands are given in Table VIII-D-2.

TABLE VIII-D-2 ESTIMATED DOMESTIC DEMANDS

	Average 77-85 Quad	Total Used	Percent Domestic Proven Reserve
Total	85		
Imported Oil	15	120	N/A
Balance	70		
Coal	16.4	131.2	0.73
Balance	53.6		
Hydro	4.0	32	100.00
Balance	49.6		
Nuclear	1.6	12.8	0.73
Balance	48.0		
Nat. Gas	16.0	127	59.00
Domestic Oil	32.0	256	113.00

The energy policy as currently conceived will leave us with some natural gas proven reserves by 1985, but crude oil proven reserves should be exhausted.

The question of transition of ultimate reserves to proven in the case of petroleum will determine how far beyond 1985 petroleum will extend. The following items will contribute to this transition.

(1) New discoveries

(2) Secondary Recovery

(3) Shale oil production

(4) Synthetic fuel production

(5) Electrification of transportation

New Discoveries: The east coast of the United States at Georges Bank, the Baltimore Canyon and the New Jersey shore all are relatively unexplored. Producing gas wells in Lake Erie have been developed by the Canadians. Environmental considerations have thus far prevented exploration in this area. In the west, the Rocky Mountain Foot Hills hold promise, and further exploration of Wyoming, Mississippi, Alabama and Utah have possibilities. Off the Gulf Coast active drilling is underway in the deeper waters off Texas and Louisiana. This exploration is some of the deepest drilling yet attempted. The contribution to proven reserves from these sources cannot be estimated. The question of when this information might be available is also highly uncertain on the positive side the number of drilling rigs active in the United States has turned up sharply since the OPEC nations started price increases. Over 1900 rigs are currently in operation. On the negative side, environmental concerns and oil pricing regulations.

Secondary Recovery: In known producing fields about 35 to 40 percent of the petroleum can be economically extracted. It has been estimated that about 60 percent of the remaining oil could be extracted by secondary recovery. Secondary recovery is achieved by flooding oil reservoirs with water, liquid gas, petroleum, carbon dioxide, or polymers. Fracturing the formation with explosives or by underground combustion to reduce viscosity of the oil, or stripping wells with low production rates may be considered as secondary recovery processes. Estimates of oil obtained from secondary recovery range from 360 to 510 quads of energy.

Shale Oil might be considered as part of the secondary recovery group. In this case, it is currently cheaper to mine the formation rather than reduce the viscosity of the oil in the formation, but in situ retorting, which is similar to underground combustion practiced in secondary recovery, has also been explored. The thickness of oil sand deposits and the concentration of oil in the sands vary. The estimated amounts of shale oil deposits are shown in Table VIII-D-3.

TABLE VIII-D-3

Potential Oil in Known Shale Oil Deposits
10 or more feet thick in Green River Formation

Greater than or equal to 25 gal. per ton	3600 quad
10 to 25 gal. per ton	8580 quad
Total.	12,180 quad

The 3600 quad figure has been included in the proven reserves of Figure VIII-D-1. Thus, it is possible that secondary recovery of oil wells and shale oil could add up to 9090 quads of energy into proven reserve category. At 85 quad per year consumption, this would provide 107 years of energy supply at the average rate between 1977 and 1985.

The rate at which secondary recovery and shale oil can contribute to national annual energy demands is not clear at present. The capital costs for new equipment, land reclamation, leasing of government lands together with increased operating costs and the price of oil will determine the rate at which these sources are brought into production. As has been shown in the earlier section on energy, the payback time, the equivalent of capital cost, and efficiency of production, and the equivalent of operating cost are higher for secondary recovery and shale oil operations. So that the number of years they could supply energy is considerably less than the 107 years estimated above.

Synthetic Fuel Production: Synthetic natural gas and synthetic liquid fuel production are both technically feasible using coal as a feed stock. The Germans produced liquid fuels from coal to support their war machinery during World War II. In terms of energy, the conversion of coal to synthetic natural gas or synthetic natural gas or synthetic liquid fuels is about 50 percent efficient. Thus, to supply the 56.1 quads of natural gas and liquid petroleum products used in 1972 would require about 112.2 quads, which together with the solid fuels already in use would bring the total demand to 125 quads per year of solid fuel. The Carter Energy Plan calls for the increase in coal production by about 60 percent by 1985 which will yield about 20 quads per year of solid fuels by that time. Solid fuel production will have to expand by about a factor of 6 if a complete transition to solid fuel were to be affected.

Transportation: Only one-tenth of one percent of the transportation energy expenditure is in the form of electricity. The electrification of railroads and possibly some intra-city transport systems might make some reduction in the liquid fuel demand, but at best, this contribution is estimated at less than 4 quad, about the same as the saving estimated for smaller autombiles.

Overview: The unbalance in our energy demands is based on our heavy dependence on liquid and gaseous petroleum products. Using our proven reserves and supplies available from secondary recovery will probably result in a declining rate of supply. A reasonable scenario for the period around 1985 would

be 90 to 95 quad per year. Total annual demand 40 to 43 quads will be in liquid petroleum and 20 to 25 quads of natural gas. Our production rate for these materials without major new discoveries will probably not exceed 15 quad each with some decline occurring each year, leaving a balance from 30 to 38 quad per year. Importing this much oil or gas does not appear feasible, but a reasonable estimate of shale oil production might be in the range of 10 quad per year. If the balance were to be obtained from coal, 20 to 28 quad of finished liquid products will be required. Hence, some 40 to 56 quad of coal must be mined to meet this demand. Solid fuel demands for electric power and industry will be at 28 to 30 quad per year indicating a total solid fuel demand of 68 to 86 quad. This would appear to exceed available production rates.

Fuel Costs and Effects on Conventional Systems

Fuel for conventional plants are expected to rise continuously as time goes on. In the case of the Texas Utilities Company, this is due to a change from 100 percent oil and gas in 1971 to 68.5 percent oil and gas in 1976, with lignite being used for the remaining 31.5 percent. By 1985, coal, lignite and nuclear are expected to carry 75 percent of the load with gas and oil being used for the remaining 25 percent. The introduction of lignite and coal require precipitation to eliminate particulate emissions from the stack. All these changes require significant capital investments for both generating plants and fuel storage facilities. The amount of profit on fuels influence the cost of generating power, but are not considered in energy payback. The National Petroleum Council, in 1971, estimated the capital investment cost for crude oil exploration at 0.84/bbl in 1970 and projected this cost to rise to 1.85/bbl by 1986, which is a rather conservative 5 percent increase per year fuel expense as published in the Texas Utilities Company Annual Report for 1976 are shown in Table VIII-D-4. In the 73 to 76 period fuel cost rose an average of 37 percent.

TABLE VIII-D-4

Fuel Cost to Texas Utilities Company $\$/10^6$ BTU

	1976	1975	1974	1973	% Increase/Year 73-76 %
Gas	1.010	.730	.435	.309	48
Oil	2.294	1.910	1.488	.985	32
Lignite	.288	.239	.181	.131	30
Weighted Average	.785	.611	.416	.304	37

The rate rise in fuel cost from 73 to 76 far exceeded the rate of increase estimates for exploration projected in 1971. The average price is also changing in a non-linear fashion due to changes in fuel, and these have a profound effect on power generating costs. For example, one can estimate that lignite supplies for Texas Utilities will last about 25 years. When

lignite is exhausted, it is planned to substitue coal and nuclear with higher costs per heat unit. The extraction efficiency, transportation and exploration costs of all fuels will rise, and more complex generation system will reduce system overall efficiency; both of which result in higher electrical costs.

There is a requirement for increased fuel facilities and expenditures to reserve fuel for future use. The planned capital expenditures of Texas Utilities gives some insight to this rising cost and is shown in Table VIII-D-5.

TABLE VIII-D-5

Planned Capital Expenditures Texas Utilities Co.

Millions of Dollars/%

Electrical Property	1976 $	1976 %	1977 $	1977 %	1978 $	1978 %	1979 $	1979 %
Production	466	68.2	552	66.5	495	67.3	548	66.0
Transmission	63	9.2	73	8.8	59	8.0	62	7.5
Distribution	64	9.3	65	7.8	74	10.0	88	10.6
General	8	1.2	7	.8	8	1.0	8	1.0
Electrical Total	601	87.9	697	83.9	636	86.3	706	85.1
Fuel Facilities								
Gas	12	1.8	14	1.7	19	2.6	8	1.0
Lignite	59	8.6	78	9.4	35	4.8	41	4.9
Coal	--	--	1	.1	10	1.4	20	.2.4
Fuel for Future Use	11	1.6	40	4.8	35	4.8	55	6.6
Fuel Total	82	12	133	16.0	99	13.6	124	14.9
Grand Total	683	100	830	100	735	100	830	100

The capital cost of generating equipment added to the system in this period remains fairly constant at about 85 percent, and the capital cost for fuel facilities is also fairly constant. However, the cost of reserving fuel for future use increases from 1.6 to 6.6 percent of the fuel capital expenditures. Fuel costs as a percent of operating costs as shown in Table VIII-D-6 also show a continuing growth for the period from 1972 to 1976 and correspond to a compound growth rate of 10 percent, a trend which would require only 3.5 years before fuel would require 100 percent of the operating budget.

Comparison of Lifetime Energy Costs of the SPS to Other Electrical Generating Systems

Background

The energy payback thus far described in last year's report is the equivalent of the energy capital investment to construct the generating station. The preceding section demonstrates that the fuel used by a power generating station does not necessarily remain the same over the plant lifetime. This, inturn, requires an additional capital energy investment to take care of plant modificationsand fuel handling facilities. Maintenance requires additional energy throughout the plants lifetime. The exploration, extraction and transportation of fuel may also change with time and require additional consideration. Another way of viewing energy payback is to consider that it reduces the overall cycle efficiency and this concept will be explored in more depth in this section. Finally, the use of a nondepletable fuel conserves depletable fuel reserves and can make significant reductions in the rate of use of these materials.

Efficiency Relationships: In Figure VIII-D-2 is shown a typical cycle involving only a generating plant. In this cycle the energy required to construct, maintain and modify the plant throughout its lifetime is seen to result in a decrease in plant efficiency.

OPERATING EXPENSES TEXAS UTILITIES
MILLIONS OF DOLLARS/%

	1972		1973		1974		1975		1976	
Operating Expense	$	%	$	%	$	%	$	%	$	%
Operation	97	23.7	100	22.0	107	19.7	124	18.0	140	16.6
Fuel	101	24.6	120	26.5	172	31.6	267	39.9	368	43.7
Maintenance	27	6.6	32	7.0	39	7.2	44	6.4	50	5.9
Direct Total	225	54.9	252	55.5	318	58.5	435	64.3	558	66.2
Taxes & Depreciation	184	45.0	201	44.5	225	41.5	251	35.7	284	33.8
Grand Total	409	100	453	100	543	100	686	100	842	100
Fuel Cost % Without Taxes		44.8		47.7		54.0		62.0		55.0

TABLE VIII-D-6

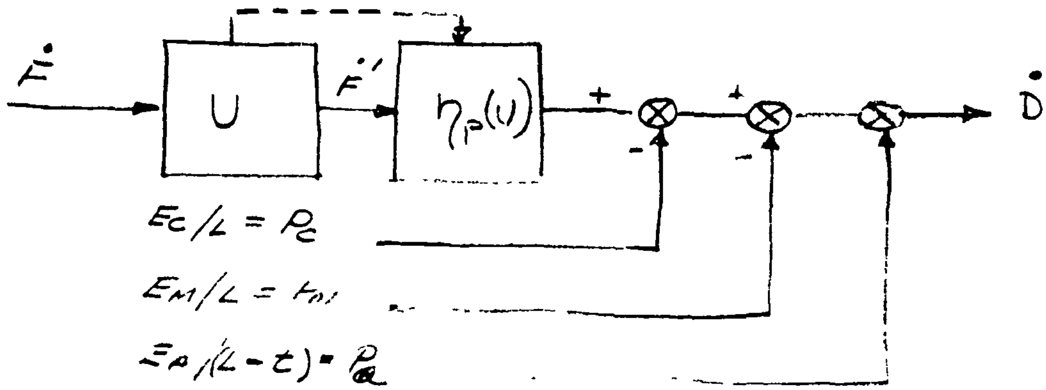


FIGURE VIII-D-2 GENERATING PLANT CYCLE

$$\dot{D}/\dot{F} = U\eta_P(U) - P_C/\dot{F} - P_M/\dot{F} - P_a/\dot{F}$$

Where:

$\dot{F}$ = Fuel Rate, Kw

U = Plant utilization factor, dimensionless (involves both power level and time)

$\eta_P(U)$ = Plant Conversion efficiency, dimensionless

E = Energy of indicated subscript

L = Plant lifetime

t = Time alteration goes on-line

P = Power loss of indicated subscript.

Subscripts:

c = Construction

m = Maintenance

a = Alteration

The factors $P_c/\dot{F}$, $P_m/\dot{F}$ and $P_a/\dot{F}$ or efficiency loss terms, designated η_{ppb}.

In a conventional plant the overall cycle efficiency is further reduced because of the energy costs of extracting, processing, refining, and delivery of fuel as shown in Figure VIII-D-3.

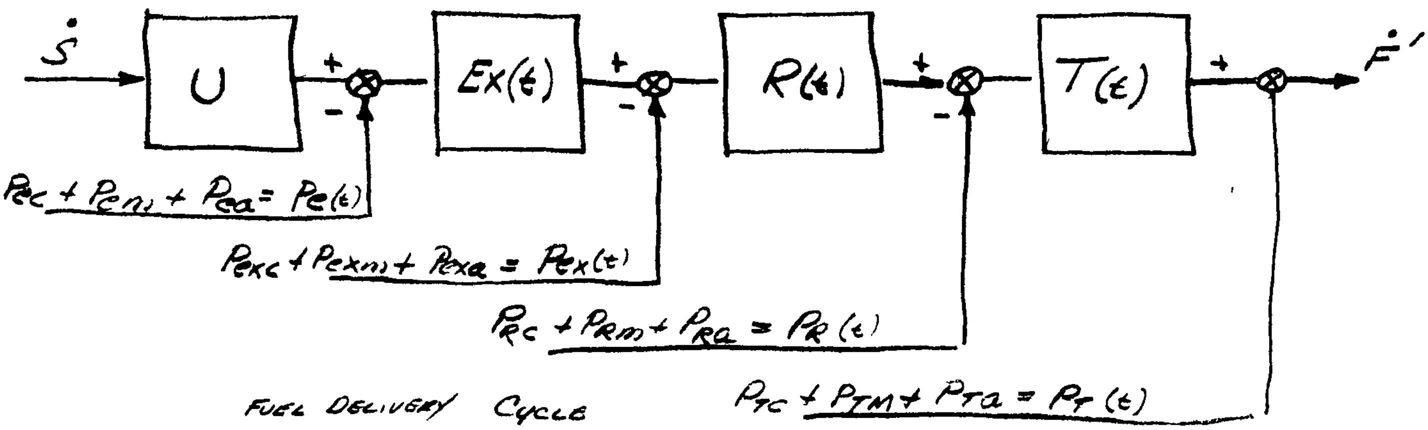


FIGURE VIII-D-3

THEN

$$\dot{F}/\dot{S} = U\,Ex\,R\,T - P_e\,Ex\,RT/\dot{S} - P_{ex}\,RT/\dot{S} - P_R\,T/\dot{S} - P_T/\dot{S}$$

Where:

$\dot{S}$ = Resource usage rate, Kw

$Ex(t)$ = Extraction efficiency, dimensionless

$R(t)$ = Refining efficiency, dimensionless

$T(t)$ = Transportation efficiency

P = Power loss for indicated subscript, Kw

Subscripts:

e = Exploration

ex = Extraction

R = Refining

t = Transportation

The first term in this equation is the efficiency of the fuel delivery cycle, η_f. The other terms are efficiency losses due to capital and operating energy expenditures to support the cycle. Hence:

$$\dot{F}'/\dot{S} = \eta_F - \eta_{FPB}$$

THEN THE OVER ALL CYCLE EFFICIENCY IS

$$\dot{O}/\dot{S} = (\dot{O}/\dot{F}')(\dot{F}'/\dot{S})$$
$$= (\eta_P - \eta_{PPB})(\eta_F - \eta_{FPB})$$

For the solar power plant, the fuel delivery cycle is unity, but as has been shown in the discussion of costs of the Texas Utility Company, the fuel delivery cycle changes with time and decreases in efficiency due to changes in fuel type and exhaustion of some sources.

Cycle Payback and Efficiency Values: Seymour Barron in "Energy Cycles - Their Cost Interrelationship for Power Generation," Mechanical Engineering, June 1976, has estimated both payback times and cycle efficiency for a number of power generating systems. Barron did not consider the effects of maintenance and alteration on efficiency and treated the fuel delivery cycle only sketchily. His relationship between electrical power per dollar and payback energy are given in Table VIII-D-7.

The solar cell payback and equivalent electrical power per dollar are based upon M. Wolf's estimates in 1972 and 1973. ERDA goals for 1986 of $500 per peak kilowatt (1975 dollars), which have been instituted since 1972, would reduce the payback period of Table VIII-D-7 to 5 years or less for ground-based cells and the use of this same technology in space would further reduce the payback period to around 1.5 years for solar cells and 2 years for the entire system. Solar cells developed specifically to meet space requirements can further reduce the payback period for the SPS to around one year, which places it in a strong competitive position with alternate systems.

TABLE VIII-D-7

CAPITAL EXPENDITURES AND ELECTRICAL POWER REQUIREMENTS FOR ENERGY CYCLE PLANTS

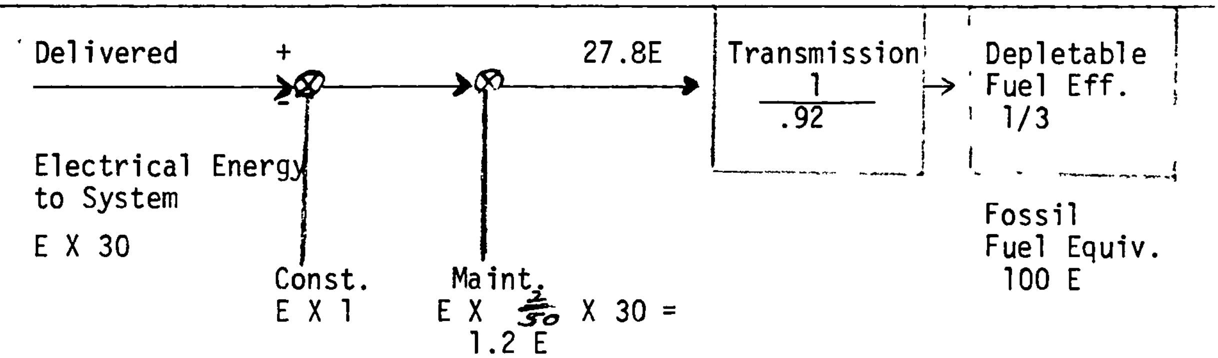
DELIVERED POWER 7.0 X 10^9 KWHR/YR

Plant Process or System	Electrical Power Requirements (Payback Energy) 10^9 KWHR	Approximate Capital Expenditures 1975	1985	Equivalent Electrical Power Per 1975 Dollars
Process Plants				
Refinery	.3	.11	.19	2.7
Stack Gas Clean Up	.2	.10	.17	2.0
Coal Gas (B_1 Gas)	1.1	.32	.54	3.4
O_2 + P.P.	.2	.08	.14	2.5
Coal Liq. (SRC)	1.5	.46	.78	3.3
O_2 + P.P.	0.1	.04	.07	2.5
LWR - Initial Core	1.0	.05	.09	20.0
Fuel Cycle	.3	.06	0.10	5.0
LMFBR	.8	.10	.17	8.0
Fuel Cycle	.2	.03	.05	6.6
Fusion - Fuel Cycle	.1	.03	.05	3.3
Liner Replacement	.8	.16	.27	5.0
Power Plants				
Oil	.6	.3	.51	2.0
Coal	.7	.33	.56	2.1
LWR	.7	.43	.73	1.6
LMFBR	1.1	.57	.97	1.9
Fusion	1.7	.80	1.36	2.1
Solar (Collectors)	54	10	17	5.4
Solar (Cells Ground Based)	331	15	25	22

Conservation of Depletable Fuel Resources by Solar Power

In this section, a first estimate of the amount of depletable fuel resources is made by comparing a space solar power system to a conventional system. A comparison is also made to a ground-based solar system and the effect of changing the construction scenario is made.

The primary advantage of solar cycles is that the fuel requirement for operation is zero. The governments interest is in conserving depletable energy resources. A more meaningful comparison between conventional fuel plants and solar power plants than energy payback for capital expenditure, is the total amount of depletable fuels used to construct, operate and maintain a conventional plant over its lifetime, compared to the amount used for a solar plant, which outputs the same energy over its lifetime. A rough estimate of the amount of net depletable energy saved by a 5 Gw SPS over its lifetime is as follows:



E = Delivered Energy/Year

$E = 10 \times 10^{7}$ Kw X .92 (plant factor) X 8760 hr/yr = 8.04×10^{10} KWhr/yr.

Fossil fuel equivalent saved over plant lifetime is:

$100 \times E = 8.04 \times 10^{12}$ Kwhr fossil fuel

$= 2.74 \times 10^{16}$ BTU

$= 4.56 \times 10^{9}$ BBL Oil

$= 2.74 \times 10^{13}$ SCF-Gas

$= 10.98 \times 10^{8}$ Ton Coal

This estimate is slightly conservative in that the capital cost of fabrication and maintenance over the plant lifetime has been ignored. Efficiency of fossil fuel extraction will decrease with time and is not taken into account.

If Scenario B of last year's JSC report were to be implemented, the fuel demand reduction per year can be estimated as shown in Table VIII-D-8. From Table VIII-D-8, the cumulative energy supplied by implementing Scenario B is about 43 percent of the proved reserves of U. S. crude in 1975. Assuming that maintenance after the construction period was the equivalent of one SPS per year as in last year's report, the operation of the 112 SPS systems over the next 30 years (year 31-61) would yield about 42.3 X 10^9 equivalent barrels of oil or about 136 percent of the proven reserves in 1977.

The effect of replacing a conventional plant, which is using fuel, by a space solar plant, which is producing fuel, is shown in Table VIII-D-9. Over the 31 years in Scenario B, the total savings is about 72 percent of the proven reserves of crude in 1977.

A comparison to a ground-based solar plant which produces the same amount of energy per year is also of interest. For this comparisons, a space power plant has a payback between 1 and 2 years. Approximately 0.75 year is in the antenna/rectenna system, the balance is associated with solar cells. The ground-based system requires a pumped storage through which must pass about three-fourths of the total power produced with an expenditure of about 40 percent of the power passing through it, would deliver approximately two-thirds of the power from the solar cells to the system. Its payback period is estimated at 0.43 years. Based upon peak flux, the ground-based solar cell system is about 1.65 times more efficient than the space system. The time averaged flux, however, is about one-fifth that received in space; hence to deliver the same energy in a year, the ground-based array would be about three times larger than a space system. If the thin solar cell proposed in the JSC report were used in space and a thick cell used on the ground, the mass of silicon in the ground array would be around 7.5 greater than in space. The payback period for the structure for the ground-based plant is estimated at 1.5 years. The total payback period for ground-based solar cell system is estimated at around 5 to 6 years. Neglecting maintenance and cell degradation, a comparison of net energy used or produced by space solar vs. ground solar cells implementation in Scenario B is shown in Table VIII-D-10. A payback period of 1.5 years is assumed for space and 5.5 years for ground solar power. For the ground solar array, it can be seen from the cumulative column that no energy is derived from the system until the 19th year, while for the space case, energy is derived from the fourth year on.

These data also demonstrates the importance of payback for space applications as the payback period increases, the less the contribution of energy to replace depletable fuels, and the longer the period before a positive energy flow is achieved.

Scenario B of the preceding JSC report has a continuously increasing construction rate, if a constant construction rate as shown in Table VIII-D-11 were established. The net energy delivered by the system over 31 years is improved by 33 percent for the one year payback period. For the 5.5 payback period, a similar improvement is shown and the break-even time on cumulative energy is reduced from 19 th 15 years.

TABLE VIII-D-8

DEPLETABLE FUEL SAVINGS BY IMPLEMENTING SCENARIO B
OF JSC 1976 REPORT, ONE YEAR PAYBACK TIME
E UNITS ARE 10 GW PLANT ENERGY OUTPUT/YEAR

Year	OPERATING UNITS	CONST. COSTS	NET OUTPUT/YR.		CUMULATIVE OUTPUT	
		E. Units		BBL Oil Equiv. X 10^7	E Units	BBL Oil Equiv. X 10^7
1	0	.5	-.5	-.635	-.5	-.635
2	0	.5	-.5	-.635	-1.0	-1.27
3	1	1	0	-1.0	-1.0	-1.27x
4	2	1	1	1.27	0	0
5	3	1	2	2.54	2	2.54
6	4	1	3	3.81	5	6.35x
7	5	1	4	5.07	9	11.43
8	6	2	4	5.07	13	16.5
9	8	2	6	7.62	19	24.1
10	10	2	8	10.14	27	34.3
11	12	2	10	12.7	37	47.0
12	14	3	11	14.0	48	61.0
13	17	3	14	17.8	62	78.7
14	20	3	17	21.5	79	100.3
15	23	3	20	25.4	99	125.0
16	26	4	22	27.9	121	153.0
17	30	4	26	33.0	147	186.7
18	34	5	29	36.8	176	223.5
19	39	5	34	43.2	210	266.7
20	49	5	39	40.5	249	316.2
21	49	6	43	54.6	292	370.8
22	55	6	49	62.2	341	433.1
23	61	6	55	69.9	396	502.9
24	67	7	61	77.47	457	580.4
25	73	6	67	85.1	524	665.5
26	79	6	73	92.71	597	758.2
27	85	6	79	100.3	676	858.5
28	91	7	84	106 6	760	965.2
29	98	7	91	115.6	851	1080
30	105	7	98	124.4	949	1205
31	112		112	142.2	1061	1347

TABLE VIII-D-9

DEPLETABLE FUEL SAVINGS BY IMPLEMENTING SCENARIO B
OF JSC 1976 REPORT, ONE YEAR PAYBACK TIME
E UNITS ARE 10 GW PLANT ENERGY OUTPUT/YEAR

Year	OPERATING UNITS	CONST. COSTS	NET OUTPUT/YR.		CUMULATIVE OUTPUT	
		E. Units	E. Units	BBL Oil Equiv. X 10^7	E. Units	BBL Oil Equiv. X 10^7
1	0	.5	-.5	-.635	-.5	-.635
2	0	.5	-.5	-.635	-1.0	-1.27
3	1	1	0	-1.0	-1.0	-1.27x
4	2	1	1	1.27	0	0
5	3	1	2	2.54	2	2.54
6	4	1	3	3.81	5	6.35x
7	5	1	4	5.07	9	11.43
8	6	2	4	5.07	13	16.5
9	8	2	6	7.62	19	24.1
10	10	2	8	10.14	27	34.3
11	12	2	10	12.7	37	47.0
12	14	3	11	14.0	48	61.0
13	17	3	14	17.8	62	78.7
14	20	3	17	21.5	79	100.3
15	23	3	20	25.4	99	125.0
16	26	4	22	27.9	121	153.0
17	30	4	26	33.0	147	186.7
18	34	5	29	36.8	176	223.5
19	39	5	34	43.2	210	266.7
20	49	5	39	40.5	249	316.2
21	49	6	43	54.6	292	370.8
22	55	6	49	62.2	341	433.1
23	61	6	55	69.9	396	502.9
24	67	7	61	77.47	457	580.4
25	73	6	67	85.1	524	665.5
26	79	6	73	92.71	597	758.2
27	85	6	79	100.3	676	858.5
28	91	7	84	106.6	760	965.2
29	98	7	91	115.6	851	1080
30	105	7	98	124.4	949	1205
31	112		112	142.2	1061	1347

TABLE VIII-D-10

IMPLEMENTATION OF SCENARIO B, COMPARISONS OF SPS AND GROUND-BASED SOLAR SYSTEMS

			SPACE				GROUND					
YEAR	CONST RATE	OPERATION	DEL POWER	CONST	NET	CUM	DEL POWER	CONST	NET	CUM	NET	CUM
1	5	0	0	75	- 75	- 75	0	2 75	-2 75	-2 75	+2	+2
2	5	0	0	75	- 75	-1 5	0	2 75	-2 75	-5 5	+2	+4
3	1	1	1	1.5	- 5	-2	1	5 5	-4 5	-10	+4	+8
4	1	2	2	1 5	+ 5	-1 5	2	5 5	-3 5	-13 5	+4	+12
5	1	3	3	1.5	+1 5	0	3	5 5	-2 5	-16	+4	+16
6	1	4	4	1.5	+2 5	+2.5	4	5 5	-1 5	-17 5	+4	+20
7	1	5	5	1.5	+3 5	+6	5	5 5	- 5	-18	+4	+24
8	2	6	6	3 0	+3 0	+9	6	11	-5	-23	+8	+32
9	2	8	8	3.0	+5 0	+14	8	11	-3	-26	+8	+40
10	2	10	10	3 0	+7	+21	10	11	-1	-27	+8	+48
11	2	12	12	3.0	+9	+30	12	11	+1	-26	+8	+48
12	3	14	14	4.5	+9 5	+39 5	14	16 5	-2 5	-28.5	+12	+68
13	3	17	17	4.5	+12 5	52	17	16 5	+ 5	-28	+12	+80
14	3	20	20	4 5	15 5	67 5	20	16 5	+3 5	-24 5	+12	+92
15	3	23	23	4 5	18 5	86	23	16 5	+6 5	-18	+12	+104
16	4	26	26	6	20	106	26	22	+4	-14	+16	+120
17	4	30	30	6	24	130	30	22	+8	-9	+16	+139
18	5	34	34	7.5	26 5	156 5	34	27 5	6 5	-2 5	+20	+159
19	5	39	39	7 5	31 5	188	39	27 5	11 5	+9	+20	+179
20	5	44	44	7.5	36 5	224 5	44	27 5	16 5	+25.5	+20	+199
21	6	49	49	9	40	264 5	49	33	16	+41 5	+24	+223
22	6	55	55	9	46	310 5	55	33	22	+63 5	+24	+247
23	6	61	61	9	52	362 5	61	33	28	+91 5	+24	+271
24	6	67	67	9	58	420 5	67	33	34	125.5	+24	+295
25	6	73	73	9	64	484 5	73	33	40	165 5	+24	+319
26	6	79	79	9	70	554 5	79	33	46	211 5	+24	+343
27	6	85	85	9	76	630 5	85	33	52	268 5	+24	+367
28	7	91	91	10 5	80 5	711	91	38 5	52 5	316	+28	+395
29	7	98	98	10 5	87.5	798 5	98	38 5	59 5	375 5	+28	+423
30	7	105	105	10 5	94 5	893	105	38 5	66.5	442	+28	+451
31	0	112	112	0	112	1005	112	0	112	554	0	+451

TABLE VIII-D-11

CONSTANT CONSTPUCTION PATE SCENARIO
COMPARING SPACE & GROUND BASED SOLAR SYSTEMS

SCENARIO			SPACE (ONE YEAR PAYBACK)				GROUND (5 5 YEAR PAYBACK)				DIFF	
YEAR	OPER	CONST	CEL P	CONST	NET	CUM	DEL P	CONST	NET	CUM	NET	CUM
1	0	1	0	1	-1	-1	0	5.5	-5.5	-5 5	-4.5	-4 5
2	1	1	1	1	0	-1	1	5.5	-4.5	-10	4.5	9
3	2	2	2	2	0	-1	2	11	-9	-19	9-	18-
4	4	4	4	4	0	-1	4	22	-18	-37	18	36
5	8	4	8	4	+4	+3	8	22	-14	-51	18	54
6	12	4	12	4	+8	+11	10	22	-12	-63	20	74
7	16	4	16	4	+12	+23	14	22	-8	-71	20	94
8	20	4	20	4	+16	+39	18	22	-4	-75	20	114
9	24	4	24	4	20	+59	22	22	0	-75	20	134
10	28	4	28	4	24	+83	28	22	+6	-69	18	152
11	32	4	32	4	28	111	32	22	+10	-59	18	170
12	36	4	36	4	32	143	36	22	+14	-45	18	188
13	40	4	40	4	36	179	40	22	+18	-27	18	206
14	44	4	44	4	40	219	44	22	+22	-5	18	224
15	48	4	48	4	44	262	48	22	26	+21	18	241
16	52	4	52	4	48	310	52	22	30	+51	18	259
17	56	4	56	4	52	362	56	22	34	+85	18	277
18	60	4	60	4	56	418	60	22	38	123	18	295
19	64	4	64	4	60	478	64	22	42	165	18	313
20	68	4	68	4	64	542	68	22	46	211	18	331
21	72	4	72	4	68	610	72	22	50	261	18	349
22	76	4	76	4	72	682	76	22	54	315	18	367
23	80	4	80	4	76	758	80	22	58	373	18	385
24	84	4	84	4	80	838	84	22	62	435	18	403
25	88	4	88	4	84	922	88	22	66	501	18	421
26	92	4	92	4	88	1010	92	22	70	571	18	439
27	96	4	96	4	92	1102	96	22	74	645	18	457
28	100	4	100	4	96	1198	100	22	78	723	18	475
29	104	4	104	4	100	1298	104	22	82	805	18	493
30	108	4	108	4	104	1402	108	22	86	891	18	511
31	112	0	112	0	112	1624	112	0	112	1003	0	621

SPS Role

The problem facing the government in the energy crisis is two-fold. First, irreplaceable fossil fuels are being depleted, and if converted from solid form to liquid form, are depleted at even more rapid rate. Second, the required rates of production will require massive capital or energy outlays, further aggravating the energy situation. The rates of production required may not be achievable. The snythetic production facilities are not even in the planning stage. The SPS could play a key role in these facilities. Thus far, we have shown that the SPS is the only new nondepletable energy source which has reached sufficient technical maturity to be available for implementation in the 1985-1990 time frame work, which can be constructed with a sufficiently short enough payback period that it can make a net contribution to the energy requirements of the nation. Further, if the SPS can be incorporated into the synthetic fuel manufacturing cycle, it will lower the demand for depletable solid resources by providing a significant fraction of the energy required for conversion to liquid fuel. This inturn reduces the demand for solid depletable materials and stretches out these materials for a longer period of time. There is no other nondepletable energy source available which can meet this problem in the time frame work of 1990.

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APPENDIX

Section VIII-C

OUTPUT FROM ENERGY PAYBACK
AND RESOURCE ANALYSIS PROGRAM FOR SPS

SOLAR POWER SATELLITE

TABLE OF CONTENTS

NOTE SUMMARY IS PRINTED AT THE END OF THE ANALYSIS

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PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW SPS

COLUMN/CABLE MICROWAVE POWER TRANSMISSION SYSTEM NOMINAL

COMPONENT	STEEL	CU	AG	AL (METRIC TONS)	ELTRNIK	RM	MUD
1.1 ROTARY JOINT							
1.1.1 AZIMUTH DRIVE							
1.1.1.1 GEARBOX	.175+03	.000	.000	.000	.000	.000	.000
1.1.1.2 MOTORS	.172+03	.255+02	.000	.000	.000	.000	.000
1.1.2 SUPPORT	.275+03	.000	.000	.000	.000	.000	.000
1.1.3 SLIP RING BRUSH	.000	.000	.117+02	.000	.000	.000	.000
1.1.4 ELEV DRIVE	.173+03	.257+02	.000	.000	.000	.000	.000
1.1.5 LUBRICANT GEARS	.000	.000	.000	.000	.000	.117-10	.000
1.1.6 LUBRICANT SLIP RINGS	.000	.000	.000	.000	.000	.117-10	.000
1.1.7 DRIVE	.128+02	.000	.000	.000	.000	.000	.000
1.1 TOTAL	.572+03	.514+02	.117+02	.000	.000	.234-10	.000

NOTE: THE VALUE .100-11, INDICATES TO BE DETERMINED

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PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW SPS

COLUMN/CABLE MICROWAVE POWER TRANSMISSION SYSTEM NOMINAL

COMPONENT	PT	SMCO	CU	GRAPHITE	STEEL	AL	ELTRNIK	MUD	GAASF
				(METRIC TONS)					
1.3 DC TO RF CONVERSION									
1.3.1 AMPLITRONS									
1.3.1.1 CATHODE	.704+01	.000	.394+02	.000	.000	.000	.000	.000	.000
1.3.1.2 MAGNETS	.000	.145+04	.000	.000	.000	.000	.000	.000	.000
1.3.1.3 ANODE	.000	.000	.534+03	.000	.000	.000	.000	.000	.000
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             .7315000E-01,  .2440000E-01,  .1418250E+00,  .5551700E+02,
             .4422500E+02
 R44     =   .0000000E+00,  .0000000E+00,  .0000000E+00,  .3000000E+00,
             .0000000E+00,  .0000000E+00,  .0000000E+00,  .0000000E+00,
             .0000000E+00,  .0000000E+00,  .0000000E+00,  .0000000E+00,
             .0000000E+00
 T304    =   .0000000E+00,  .0000000E+00,  .0000000E+00,  .0000000E+00,
             .4519860E+02,  .0000000E+00,  .3183000E-11,  .0000000E+00,
             .0000000E+00,  .0000000E+00,  .0000000E+00,  .0000000E+00,
             .0000000E+00
$END
```

PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW SPS

COLUMN/CABLE MICROWAVE POWER TRANSMISSION SYSTEM NOMINAL

COMPONENT	AL	STEEL	CU	ELTRNIK (METRIC TONS)	RM	MUD
1.3 TRANSMIT ANTENNA						
1.3.1 SLOTTED WAVE GUIDE	.400+04	.000	.000	.000	.000	.000
1.3.2 WAVEGUIDE/STRUCT INTERFACE						
1.4.2.1 SHAFT	.000	.593+03	.000	.000	.000	.000
1.4.2.2 WORM	.000	.113+03	.000	.000	.000	.000
1.4.2.3 MOTOR 30/20	.000	.235+03	.512+02	.000	.000	.000
1.4.2.4 THERMAL ISOLATION	.000	.000	.000	.000	.000	.452+02
1.3.2.5 GEARBOX AND GIMBAL	.000	.197+03	.000	.000	.000	.000
1.4.2.6 LUBRICANT	.000	.000	.000	.000	.000	.318-11
1.4.2.7 CONDUCTORS (MOTORS)	.318-11	.000	.000	.000	.000	.000
1.3.2 TOTAL	.318-11	.111+04	.512+02	.000	.000	.452+02
1.3.3 ATTITUDE-CONTROL/ALIGNMENT						
1.3.3.1 COMMUNICATION S. S.	.000	.000	.000	.702-01	.000	.000
1.4.3.2 CPU AND MEMORY	.000	.000	.000	.244-01	.000	.000
1.3.3.3 ATTITUDE SENSORS	.000	.000	.000	.142+00	.000	.000
1.4.3.4 SUBARRAY CONTROL	.000	.000	.000	.555+02	.000	.000
1.4.3.5 SCREWJACK ACTUATORS	.000	.000	.000	.842+02	.000	.000
1.4.3 TOTAL	.000	.000	.000	[illegible]	.000	.000

NOTE: THE VALUE .100-11, INDICATES TO BE DETERMINED.

```
$DATS,
ALS    =   .13700000E+03,   .47000000E+02,   .10500000E+03,   .54000000E+02,
           .10000000E+00,   .23000000E+02
STS    =   .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
           .00000000E+00,   .00000000E+00
CDS    =   .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
           .00000000E+00,   .00000000E+00
ELS    =   .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
           .00000000E+00,   .00000000E+00
RMS    =   .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
           .00000000E+00,   .00000000E+00
TBDS   =   .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
           .21000000E+02,   .00000000E+00
$END
```

PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW SPS

COLUMN/CABLE MICROWAVE POWER TRANSMISSION SYSTEM NOMINAL

COMPONENT	AL	STEEL	CU	ELTRNIK (METRIC TONS)	RM	MUD
1.4.4 ANTENNA STRUCTURE						
1.4.4.1 SUBARRAY PRIMARY	.137+03	.000	.000	.000	.000	.000
1.4.4.2 SUBARRAY SECONDARY	.470+02	.000	.000	.000	.000	.000
1.4.4.3 SUPPORT STRUCTURE	.105+03	.000	.000	.000	.000	.000
1.4.4.4 YOKE	.540+02	.000	.000	.000	.000	.000
1.4.4.5 COATINGS	.000	.000	.000	.000	.000	.210+02
1.4.4.5 AMPLITRON ATTACH	.230+02	.000	.000	.000	.000	.000
1.4.4 TOTAL	.367+03	.000	.000	.000	.000	.210+02
1.4 TOTAL	.437+04	.111+04	.512+02	.100+03	.000	.660+02

NOTE: THE VALUE .100-11, INDICATES TO BE DETERMINED.

I

BOATS
PTS .000000E+00, .700000E-15, .000000E+00, .000000E+00,

```
$DATS
 PTS     =  .000000000E+00,  .700000000E-05,  .000000000E+00,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 SMCDS   =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 CJS     =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .215000000E+04,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 GRPS    =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 STS     =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 ALS     =  .135000000E+07,  .100000000E-12,  .100000000E-12,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 ELS     =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
            .100000000E-11,  .100000000E-11,  .000000000E+00
 TBDS    =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .100000000E-11
 GAASS   =  .000000000E+00,  .600000000E+01,  .000000000E+00,  .000000000E+00,
            .000000000E+00,  .000000000E+00,  .000000000E+00
 CONCRT  =  .152000000E+07
 $END
```

PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW

MICROWAVE POWER TRANSMISSION GROUND SYSTEM

COMPONENT	PT	SMCO	CU	GRPHITE (METRIC TONS)	STEEL	AL	ELTRNIK	MUD	GAAS
1.5 RECTENNA									
1.5.1 RECTIFIER									
1.5.1.1 DIPOLE AND FILTERS	.000	.000	.000	.000	.000	.163+07	.000	.000	.000
1.5.1.2 DIODE	.350-05	.000	.000	.000	.000	.120-12	.000	.000	.720
1.5.1.3 REFLECTOR	.000	.000	.000	.000	.000	.120-12	.000	.000	.000
1.5.1.4 D.C. BUSSES	.000	.000	.258+04	.000	.000	.000	.000	.000	.000
1.5.1.5 INVERTERS	.000	.000	.000	.000	.000	.000	.120-11	.000	.000
1.5.1.5 GROUND BEAM CONTROL	.000	.000	.000	.000	.000	.000	.120-11	.000	.000
1.5.1.7 STRUCTURAL SUPPORT	.000	.000	.000	.000	.000	.000	.000	.100-11	.000
1.5.1 TOTAL	.360-05	.000	.258+04	.000	.000	.163+07	.240-11	.000	.720

NOTES: THE VALUE .100-11, INDICATES TO BE DETERMINED
THE VALUE .100-12, INDICATES INCLUDED IN DIPOLE & FILTERS
SECTION 1.5 IS GROUND EQUIPMENT ONLY
AND INCLUDES 1.2 GROWTH FACTOR

PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW

COLUMN/CABLE MICROWAVE POWER TRANSMISSION SYSTEM SUMMARY NOMINAL

COMPONENT	AL	STEEL	CU	AG (METRIC TONS)	PT	SMCO	GRPHITE
1.1 ROTARY JOINT	.000	.572+03	.514+02	.117+02	.000	.000	.000
1.2 INPUT POWER DISTRIBUTION	.167+02	.000	.000	.000	.000	.000	.000
1.3 DC TO RF CONVERSION	.000	.846+03	.730+03	.000	.704+01	.145+04	.584+04
1.4 TRANSMIT ANTENNA	.437+04	.111+04	.512+02	.000	.000	.000	.000
1.1-1.4 FLIGHT TOTAL	.438+04	.253+04	.833+03	.117+02	.704+01	.145+04	.584+04
1.5 RECTENNA (GROUND)	.163+07	.000	.256+04	.000	.360-05	.000	.000
1.0 TOTAL	.164+07	.253+04	.336+04	.117+02	.704+01	.145+04	.584+04

NOTE: THE VALUE .100-11, INDICATES TO BE DETERMINED

PART 2

NONCONSUMABLES

MATERIAL REQUIREMENTS FOR 10GW

COLUMN/CABLE MICROWAVE POWER TRANSMISSION SYSTEM SUMMARY NOMINAL (CONT

(METRIC TONS)

COMPONENT	MJD
1.1 ROTARY JOINT	.000
1.2 INPUT POWER DISTRIBUTION	.000
1.3 DC TO RF CONVERSION	.000
1.4 TRANSMIT ANTENNA	.562+02
1.1-1.4 FLIGHT TOTAL	.562+02
1.5 RECTENNA (GROUND)	.000
1.0 TOTAL	.562+02

NOTE: THE VALUE .100-11, INDICATES TO BE DETERMINED

```
$RATIO
AREA   =  .433437000E+02,  .716920000E+02,  .914400000E+02
UMASS  =  .310000000E+03,  .400000000E+03,  .450000000E+03,  .167000000E+02,
          .220000000E+02
BUSBAR =  .140318000E+04,  .212138000E+04,  .256732500E+04,  .181694000E+04,
          .271133000E+04,  .745370000E+04,  .209773000E+04,  .311995000E+04,
          .397947000E+04
FACT1  =  .496770000E+00,  .177400000E+00,  .116130000E+00,  .177420000E+00,
          .022500000E-01,  .610000000E+00,  .137000000E+00,  .900000000E-01,
          .137500000E+00,  .250000000E-01,  .558599900E+00,  .119560000E+00,
          .732599990E-01,  .119560000E+00,  .217400000E-01
DIST   =  .155300000E+04,  .213200000E+04,  .449500000E+04,  .575000000E+03,
          .157300000E+04,  .254500000E+04,  .235800000E+04,  .358000000E+04,
          .519300000E+04,  .112000000E+04,  .320000000E+04,  .448000000E+04,
          .411700000E+04,  .159500000E+04,  .115020000E+05,  .168000000E+04,
          .449300000E+04,  .632700000E+04
STRUCT =  .290000000E+03,  .322000000E+03,  .338000000E+03,  .345100000E+04,
          .334500000E+04,  .461400000E+04,  .398000000E+03,  .431000000E+03,
          .517000000E+03,  .516300000E+04,  .573400000E+04,  .598500000E+04,
          .455000000E+03,  .513000000E+03,  .521000000E+03,  .558650000E+04,
          .731800000E+04,  .878100000E+04
OTHER  =  .253000000E+03,  .329000000E+03,  .455000000E+03
GOLD   =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00
CU11   =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00
PAINT  =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00
MYLAR  =  .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00,  .000000000E+00,
          .000000000E+00,  .000000000E+00,  .000000000E+00
PROP   =  .670000000E+02,  .900000000E+02,  .930000000E+02,  .860000000E+02,
          .104000000E+03,  .119000000E+03,  .980000000E+02,  .113000000E+03,
          .139000000E+03,  .128000000E+03,  .155000000E+03,  .178000000E+03,
          .127000000E+03,  .143000000E+03,  .179000000E+03,  .163000000E+03,
          .193000000E+03,  .227000000E+03
$END
```

PART 2

NONCONSUMABLES

COLUMN/CABLE SOLAR CELL COLLECTION SYSTEM BASELINE SYSTEM 10GW
NOMINAL BLANKET UNIT MASS OF 400.00 GRAMS/SQ METERS
NOMINAL BLANKET AREA OF 71.592 X10+3 SQ METERS

COMPONENT	SILICON	TEFLON	KAPTON	AL (METRIC TONS)	AR	MUD	TOTAL
2.1 SOLAR CELL							
2.1.1 SOLAR CELL .1MM	.175+05	.000	.000	.000	.000	.000	.17493+05
2.1.2 COVER .025MM	.000	.394+04	.000	.000	.000	.000	.39431+04
2.1.3 BUSS BAR	.000	.000	.000	.271+04	.000	.000	.27113+04
2.1.4 INTERCONNECT	.000	.000	.000	.717+03	.000	.000	.71692+03
2.1.5 THERMAL COAT	.000	.000	.000	.000	.000	.000	.00000
2.1.6 SUBSTRATE	.000	.394+04	.258+04	.000	.000	.000	.65240+04
2.1 TOTAL	.175+05	.789+04	.258+04	.343+04	.000	.000	.31398+05
2.2 POWER DIST. BUS AND SWITCHES	.000	.000	.000	.389+04	.000	.000	.38860+04
2.3 ALUMINIZED REFLECTORS	.000	.000	.129+04	.158+04	.000	.000	.28677+04
2.4 STRUCTURAL NON-CONDUCTING	.000	.000	.000	.431+03	.000	.000	.43100+03
2.5 OTHER SYSTEMS	.000	.000	.000	.000	.000	.329+03	.32900+03
2.0 TOTAL	.175+05	.789+04	.337+04	.932+04	.000	.329+03	.38902+05

NOTE: THE VALUE .100-11, INDICATES TO BE DETERMINED

```
$DAT12
 ADJ14 =   .225950000E+05,   .956740000E+05,   .525020000E+05,   .142722000E+06,
           .133650000E+05,   .000000000E+03,   .219420000E+05,   .190530000E+05,
           .355000000E+04,   .204000000E+03,   .123000000E+04,   .442600000E+04,
           .238148000E+06,   .368250000E+05,   .000000000E+00,   .128550000E+05,
           .115600000E+04,   .466610000E+04,   .213990000E+05,   .367000000E+03,
           .332000000E+03,   .737000000E+03,   .156030000E+05,   .152574000E+06,
           .114510000E+05,   .150620000E+05,   .102400000E+04,   .335100000E+04,
           .455730000E+05,   .744600000E+05,   .345780000E+05
 HLLVLD =            .454
$END
```

PART 2

NONCONSUMABLES

4.3 HEAVY LAUNCH VEHICLE - 2 STAGE BALLISTIC

LOX/RP-1 FUELED STAGE 1 WITH 454 METRIC TON PAYLOAD

(METRIC TONS)

COMPONENT	MUD
4.1 BODY STRUCTURE	
4.1.1 FORWARD SKIRT	.103+02
4.1.2 LOX TANK	.434+02
4.1.3 FUEL TANK	.239+02
4.1.4 THRUST STRUCTURE	.549+02
4.1.5 BASE SKIRT	.320+01
4.1 TOTAL	.151+03
4.2 THERMAL PROTECTION	
4.2.1 ENTRY HEAT SHIELD	.996+01
4.2.2 FLAME SHIELD	.332+01
4.2.3 INTER-TANK INSULATION	.156+01
4.2.4 BODY ENTRY COVER PANELS	.926-01
4.2 TOTAL	.235+02
4.3 ELECTRICAL POWER SYSTEM	.558+00
4.4 INSTRUMENTATION	.201+01
4.5 PROPULSION	
4.5.1 DRY ENGINES	.131+03
4.5.2 CONTROL SYSTEM	.157+02
4.5.3 FUEL SYSTEM	.300
4.5.4 OXIDIZER SYSTEM	.492+01
4.5 TOTAL	.152+03

PART 2

NONCONSUMABLES

4.0 HEAVY LAUNCH VEHICLE -2 STAGE BALLISTIC (CONTINUED)

LOX/RP-1 FUELED STAGE 1 WITH 454 METRIC TON PAYLOAD

(METRIC TONS)

COMPONENT	MOD
4.5 MISC. ITEMS	.529+00
4.7 SEPARATION AND RECOVERY	
4.7.1 SEPARATION SYSTEM	.212+01
4.7.2 PARACHUTES	.972+01
4.7.3 FLOTATION SYSTEM	.176+00
4.7.4 RECOVERY AIDS	.173+00
4.7.5 FITTING AND SUPPORTS	.335+00
4.7.6 RETRO MOTORS	.717+01
4.7 TOTAL	.197+02
4.8 CONTINGENCY	.593+02
4.9 RESIDUAL AND RESERVE PROP	
4.9.1 FUEL BIAS	.520+01
4.9.2 LOX TANK VAPORS	.534+01
4.9.3 FUEL TANK VAPORS/GASES	.455+00
4.9.4 TRAPPED FROST	.152+01
4.9.5 TRAPPED FUEL (TANK)	.211+02
4.9.6 TRAPPED LOX (TANK)	.339+02
4.9.7 TRAPPED PROP (ENGINES)	.157+02
4.9 TOTAL	.347+02
4.0 TOTAL	.530+03

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$DAT13
WDOTS =      .11329700E+05,   .40793000E+05,   .11195700E+05,   .76490000E+05,
             .63588000E+04,   .23197000E+05,   .15559000E+05,   .16670000E+04,
             .25133000E+04,   .21400000E+03,   .72900000E+03,   .39150000E+04,
             .64564000E+05,   .74900000E+04,   .74900000E+03,   .30000000E+00,
             .12520000E+04,   .18300000E+03,   .13519000E+05,   .19000000E+03,
             .13800000E+03,   .36200000E+03,   .77680000E+04,   .74578000E+05,
             .75450000E+04,   .22767000E+05,   .59230000E+04,   .00000000E+00,
             .11340000E+05,   .12643000E+05,   .57690000E+04,   .90000000E+03
$END
```

PART 2

NONCONSUMABLES

5.3 HEAVY LAUNCH VEHICLE -2 STAGE BALLISTIC

LOX/LH2 FUELED STAGE 2 WITH 454 METRIC TON PAYLOAD

(METRIC TONS)

COMPONENT	MOD
5.1 BODY STRUCTURE	
5.1.1 FORWARD SKIRT	.542+01
5.1.2 LOX TANK	.135+02
5.1.3 FUEL TANK	.508+02
5.1.4 THRUST STRUCTURE	.156+02
5.1.5 BASE SKIRT	.330+01
5.1.6 AFT SKIRT	.105+02
5.1 TOTAL	.105+03
5.2 THERMAL PROTECTION	
5.2.1 ENTRY HEAT SHIELD	.752+01
5.2.2 FLAME SHIELD	.757+00
5.2.3 INTER-TANK INSULATION	.119+01
5.2.4 BODY ENTRY COVER PANELS	.972-01
5.2 TOTAL	.956+01
5.3 ELECTRICAL POWER SYSTEM	.331+00
5.4 INSTRUMENTATION	.178+01
5.5 PROPULSION	
5.5.1 DRY ENGINES	.335+02
5.5.2 CONTROL SYSTEM	.340+01
5.5.3 FUEL SYSTEM	.340+00
5.5.4 OXIDIZER SYSTEM	.300
5.5 TOTAL	.423+02

PART 2

NONCONSUMABLES

5.3 HEAVY LAUNCH VEHICLE -2 STAGE BALLISTIC (CONTINUED)

LOX/LH2 FUELED STAGE 2 WITH 454 METRIC TON PAYLOAD

(METRIC TONS)

COMPONENT	MUD
5.6 MISC. ITEMS	.560+00
5.7 SEPARATION AND RECOVERY	
5.7.1 SEPARATION SYSTEM	.331-01
5.7.2 PARACHUTES	.479+01
5.7.3 FLOTATION SYSTEM	.963-01
5.7.4 RECOVERY AIDS	.354-01
5.7.5 FITTING AND SUPPORTS	.154+00
5.7.6 RETRO MOTORS	.353+01
5.7 TOTAL	.372+01
5.8 CONTINGENCY	.339+02
5.9 RESIDUAL AND RESERVE PROP	
5.9.1 FUEL BIAS	.347+01
5.9.2 LOX TANK VAPORS	.103+02
5.9.3 FUEL TANK VAPORS/GASES	.269+01
5.9.4 TRAPPED FROST	.000
5.9.5 TRAPPED FUEL (TANK)	.501+01
5.9.6 TRAPPED LOX (TANK)	.574+01
5.9.7 TRAPPED PROP (ENGINES)	.336+01
5.9 TOTAL	.333+02
5.10 AERODYNAMIC FAIRINGS	.439+00
5.3 TOTAL	.233+03

```
$DATI4
COTVLD =                 250
COTVW1 =      .27000000E+02,   .35000000E+02,   .43000000E+02
COTVW2 =      .70000000E+01,   .90000000E+01,   .11000000E+02
POTVLD =                 240,             230,             2[illegible]5
POTVWT =      .27000000E+02,   .35000000E+02,   .43000000E+02
PLVLD  =                  50
PLVOR3 =      .65000000E+02
PLVET  =      .33000000E+02
PLVLR3 =      .13300000E+03
H_LVLD =                 454
LEDBAS =      .60000000E+04
SEDBAS =      .10000000E+04

$END
```

PART 2

NONCONSUMABLES

6.3 CARGO ORBITAL TRANSFER VEHICLE 2-1/2 STAGE NOMINAL
LOX/LH2 FUELED WITH 250 METRIC TON PAYLOAD

TOTAL INERT WEIGHT (METRIC TONS) = .3570D+02

EXPANDED INERT WEIGHT (METRIC TONS) = .9600D+01

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PART 2

NONCONSUMABLES

7.0 PERSONNEL LAUNCH VEHICLE -MODIFIED SHUTTLE
LOX/LH2 EXTERNAL TANKS AND LOX/RP1 LIQUID ROCKET BOOSTER
WITH 50 PASSENGER PAYLOAD

ORBITER INERT WEIGHT (METRIC TONS) = .8500+04

EXTERNAL TANK INERT WEIGHT (METRIC TONS) = .3300+04

LR BOOSTER INERT WEIGHT (METRIC TONS) = .1380+03

PART 2

NONCONSUMABLES

6.3 PERSONNEL ORBITAL TRANSFER VEHICLE 2-1/2 STAGE NOMINAL
LOX/LH2 FUELED WITH 230 PASSENGER PAYLOAD

TOTAL INERT WEIGHT (METRIC TONS) = .3500+02

```
 $DATIS
 HLLVFD  =   .44410000E+04,   .44410000E+04,   .19370000E+04,   .20450000E+04
 DTVFDL  =   .45300000E+03,   .47500000E+03,   .49[illegible]00000E+03
 DTVFLS  =   .13500000E+03,   .14300000E+03,   .14700000E+03
 PLVFDL  =   .55700000E+03,   .13250000E+04,   .[illegible]E+0[illegible]
 HLLVTN  =   .93010000E+01
 DTVTN   =   .50000000E+01,   .75000000E+01,   .10000000E+02
 PLVTN   =   .11000000E+02
 HLLVLF  =   .30000000E+03
 DTVLF   =   .50000000E+02,   .30000000E+02,   .20000000E+02
 PLVLF   =   .10000000E+03
 ICREW   =              +0,              +5,              +0,              +1,
                        +2
 PAYE    =   .24570000E+02,   .13890000E+01,   .12349400E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .24570000E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .77780000E+01,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .24570000E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .55127000E+03,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .24570000E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .11340000E+01,   .49260000E+02,
             .40000000E+01,   .24570000E+02,   .24570000E+02,   .00000000E+00
 HE      =   .10000000E-11,   .10000000E-11,   .10000000E-11,   .10000000E-11,
             .10000000E-11
 $END
```


C-9

```
$DATIS
 HLLOFJ  =   .44410000E+04,   .44100000E+04,   .19370000E+04,   .20550000E+04
 DIOFJL  =   .45300000E+03,   .47500000E+03,   .49400000E+03
 DIOFLS  =   .13500000E+03,   .14300000E+03,   .14700000E+03
 PLOFJL  =   .55700000E+03,   .13250000E+04,   .33000000E+03
 HLLOTN  =   .97000000E+02
 DIOIN   =   .53000000E+01,   .70000000E+01,   .13070000E+02
 PLOIN   =   .11300000E+02
 HLLOLF  =   .33300000E+03
 DIOLF   =   .57300000E+02,   .30000000E+02,   .23000000E+02
 PLOLF   =   .13000000E+03
 IEVEL   =            +0,              +5,              +0,              +0,
                      +0
 PAVE    =   .24570000E+02,   .13890000E+01,   .12343400E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .24570000E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .77178000E+03,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .24570000E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .55127000E+03,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .24570000E+02,   .24570000E+02,
             .24570000E+02,   .24570000E+02,   .11340000E+01,   .49260000E+02,
             .40000000E+01,   .24570000E+02,   .24570000E+02,   .00000000E+00
 WE      =   .10000000E-11,   .10000000E-11,   .10000000E-11,   .10000000E-11,
             .10000000E-11
$END
```

PART 3

CONSUMABLES

1.0 VEHICLE FLIGHT DATA

1.1
HEAVY LIFT LAUNCH VEHICLE-2 STAGE BALLISTIC   CAPE LAUNCH TO INCLINED ORBIT
LOX/RP-1   FUELED FIRST STAGE FOR A 454 METRIC TON PAYLOAD

CONSUMABLES/FLIGHT (METRIC TONS)

LOX	3207.39
LH2	.00
RP-1	1233.61
C3H8	.00
HE	.1000-11
TOTAL	4441.00
PERSONNEL	0
PERSONNEL CONSUMABLES	
FOOD	NA
PERSONAL EQUIPMENT	NA
REPLACMENT PARTS	TBD
TURNAROUND TIME (DAYS)	9.
AIRFRAME LIFE (FLTS)	300.
ENGINE LIFE (FLTS)	300.
REFURBISHMENT MATERIAL	TBD

E VALUE .100E-11, INDICATES TO BE DETERMINED

PART 3

CONSUMABLES

1.0 VEHICLE FLIGHT DATA (CONTINUED)

1.1
HEAVY LIFT LAUNCH VEHICLE-2 STAGE BALLISTIC   CAPF LAUNCH TO INCLINED ORBIT
LOX/LH2 FUELED SECOND STAGE FOR A 454 METRIC TON PAYLOAD

CONSUMABLES/FLIGHT (METRIC TONS)

LOX	1660.29
LH2	275.71
RP-1	.00
C3H8	.00
HE	.1000-11
TOTAL	1937.00
PERSONNEL	0
PERSONNEL CONSUMABLES	
FOOD	NA
PERSONAL EQUIPMENT	NA
REPLACEMENT PARTS	TBD
TURNAROUND TIME (DAYS)	9.
AIRFRAME LIFE (FLTS)	200.
ENGINE LIFE (FLTS)	300.
REFURBISHMENT MATERIAL	TBD

THE VALUE .100E-11, INDICATES TO BE DETERMINED

PART 3

CONSUMABLES

1.0 VEHICLE FLIGHT DATA (CONTINUED)

1.2
PERSONNEL LAUNCH VEHICLE - MODIFIED SHUTTLE
CAPE LAUNCH TO INCLINED ORBIT
LOX/LH2 EXTERNAL TANK FOR A 50 PASSENGER PAYLOAD

CONSUMABLES/FLIGHT (METRIC TONS)

LOX	436.00
LH2	31.00
RP-1	.00
CH4	.00
HE	.1000-11
TOTAL	567.00
PERSONNEL	5
PERSONNEL CONSUMABLES	
FOOD	NA
PERSONAL EQUIPMENT	NA
REPLACMENT PARTS	TBD
TURNAROUND TIME (DAYS)	11.
AIRFRAME LIFE (FLTS)	100.
ENGINE LIFE (FLTS)	100.
REFURBISHMENT MATERIAL	TBD

THE VALUE .100E-11, INDICATES TO BE DETERMINED

PART 3

CONSUMABLES

1.0 VEHICLE FLIGHT DATA (CONTINUED)

1.2
PERSONNEL LAUNCH VEHICLE - MODIFIED SHUTTLE
CAPE LAUNCH TO INCLINED ORBIT
LOX/RP-1 BOOSTER STAGE FOR A 50 PASSENGER PAYLOAD

CONSUMABLES/FLIGHT (METRIC TONS)

LOX	919.80
LH2	.00
RP-1	405.20
C3H8	.00
HE	.1000-11
TOTAL	1325.00
PERSONNEL	5
PERSONNEL CONSUMABLES	
FOOD	NA
PERSONAL EQUIPMENT	NA
REPLACEMENT PARTS	TBD
TURNAROUND TIME (DAYS)	11.
AIRFRAME LIFE (FLTS)	100.
ENGINE LIFE (FLTS)	100.
REFURBISHMENT MATERIAL	TBD

THE VALUE .100E-11, INDICATES TO BE DETERMINED

1.3
CARGO ORBITAL TRANSFER VEHICLE 2-1/2 STAGE NOMINAL
LOX/LH2 FUELED FOR A 250 METRIC TON PAYLOAD

LOX	529.71
LH2	88.29
RP-1	.00
C3H8	.00
HE	.1000E-11
TOTAL	618.00
PERSONNEL	0
PERSONNEL CONSUMABLES	
FOOD	NA
PERSONAL EQUIPMENT	NA
REPLACMENT PARTS	TBD
TURNAROUND TIME (DAYS)	7.
AIRFRAME LIFE (FLTS)	30.
ENGINE LIFE (FLTS)	30.
REFURBISHMENT MATERIAL	TBD

OTV FUELS INCLUDE LOSSES

THE VALUE .100E-11, INDICATES TO BE DETERMINED

PART 3

CONSUMABLES

1.0 VEHICLE FLIGHT DATA (CONTINUED)

1.4
PERSONNEL ORBITAL TRANSFER VEHICLE 2-1/2 STAGE NOMINAL
LOX/LH2 FUELED WITH A 230 PASSENGER PAYLOAD

LOX	529.71
LH2	35.29
RP-1	.00
CH4	.00
HE	.1000-11
TOTAL	565.00
PERSONNEL	0
PERSONNEL CONSUMABLES	
FOOD	NA
PERSONAL EQUIPMENT	NA
REPLACMENT PARTS	TBD
TURNAROUND TIME (DAYS)	7.
AIRFRAME LIFE (FLTS)	30.
ENGINE LIFE (FLTS)	30.
REFURBISHMENT MATERIAL	TBD

OTV FUELS INCLUDE LOSSES

THE VALUE .100E-11, INDICATES TO BE DETERMINED

2.3 CONSUMABLES SUMMARY NOMINAL

(METRIC TONS)

VEHICLE	SYSTEM	MASS TO ORBIT	FLIGHTS	LOX	LH2	PROPELLANT RP1	C3H8	HE
HLLV 454 PAYLD BALLISTIC	MPTS	.5311+05	.1230+13	.5230+05	.3542+05	.1579+06	.0000	.100
	SECS	.1400+05	.3034+03	.1501+07	.8535+05	.3805+06	.0000	.100
COTV	MPTS	.1584+05	.6330+02	.3357+05	.5595+04	.0000	.0000	.100
	SECS	.3947+05	.1576+33	.5349+05	.1371+05	.0000	.0000	.100
TOTAL		.12735 x 10^6		.2241+07	.1403+06	.5384+06	.0000	.100

NOTE OTV PROPELLANTS INCLUDE LOSSES

SECS ORIENTATION SYSTEM

1 YEAR SUPPLY (METRIC TONS) .1130+03

THE VALUE .1000E-11, INDICATES TO BE DETERMINED

Cost of Transport ; COTV & COTV Fuel ??

PART 4

TOTAL MATERIALS REQUIREMENT-NONCONSUMABLES MATERIALS SUMMARY (METRIC TONS)

MATERIAL	MPTS	SECS	HLLV	ASSEMBLY	COTV	POV	POTV	LEO BASE	GEO BASE	FLTTOTAL	GNDT
AL	.4734+04	.9322+04			.0000					.1371+05	.153
STEEL	.2531+04		.0000		.0000					.2531+04	.000
CU	.8025+03	.0000	.0000		.0000					.8025+03	.258
AG	.1170+02									.1170+02	.000
PT	.7142+01									.7042+01	.350
SMCO	.1447+04									.1447+04	.000
GRAPHITE	.5645+04									.5645+04	.000
GAAS	.0000									.0000	.720
ELECT	.2295+03		.0000		.0000					.2295+03	.240
RM	.2053+02									.2068+02	.001
CONCRETE											.15.
SILICON		.1749+05								.1749+05	
TEFLON		.7385+04								.7885+04	
KAPTON		.3371+04								.3871+04	
W			.0000							.0000	
MO			.0000							.0000	
CERMISK			.0000							.0000	
STAIN-STEEL			.0000							.0000	
INSULAT					.0000					.0000	
INCONEL					.0000					.0000	
MJD	.5620+02	.3290+03	.1067+04		.3241+03			.6670+04	.1000+04	.8787+04	.001
TOTAL	.1534+05	.3390+05	.1067+04		.3241+03			.5000+04	.1000+04	.6264+05	.31

TOTAL ENERGY PAYBACK (YEARS)

	MPTS	SECS	HLLV	ASSEMBLY	COTV	POV	POTV	LEO BASE	GEO BASE	FLTTOTAL	GNDT
KNOWN	.1537-02	.2905-02	.0000		.0000			.0000	.0000	.4442-02	.52
AL LIKE MAT.	.2057-02	.9116-02	.3327-03		.1010-03			.1870-02	.3116-03	.1479-01	.22
NON-CON TOT	.3693-02	.1202-01	.3327-03		.1010-03			.1670-02	.3116-03	.1853-01	.52
CONSUM TOT	.0000	.0000	.1333+00		.1387-01			.0000	.0000	.1472+00	.00
TOTAL	.3693-02	.1202-01	.1337+00		.1397-01			.1670-02	.3116-03	.1657+00	.62

~~SNOTOF PAYBACK TOTAL INCLUDES AN ADDITIONAL .1 YEAR FOR GROUND GRADING~~

THE VALUE .100E-11, INDICATES TO BE DETERMINED

PART 4

ENERGY PAYBACK TABLE

(KWH/MT)

MATERIAL	ENERGY TO PRODUCE	MATERIAL	ENERGY TO PRODUCE
AL	.2457+05	W	.2457+05 *
ST	.1339+04	MO	.2457+05 *
CU	.1235+05	CERMIC	.2457+05 *
AG	.2457+05 *	STST	.5513+06
PT	.2457+05 *	INSU	.2457+05 *
SMCO	.2457+05 *	INC	.2457+05 *
GRAPH	.2457+05 *	MUD	.2457+05 *
GAAS	.2457+05 *	LOX	.1134+04
ELECT	.2457+05 *	LH2	.4926+05
RM	.2457+05 *	RP1	.4000+04
CONCRT	.7718+03	C3H8	.2457+05 *
SI	.2457+05 *	HE	.2457+05 *
TEFLON	.2457+05 *	N2	.0000
KAPTON	.2457+05 *		

* PAYBACKS ASSUMED TO BE SIMILAR TO AL

N2 ENERGY PAYBACK IS INCLUDED IN LOX

SORTED
MJS

MJ

PDJS

	.1000000000E-14,	.1000000000E-14,	.2415000000E+11,	.1754000000E+11,
	.1400000000E+11,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1700000000E-14,	.9370000000E+05,
	.8740000000E+05,	.6840000000E+05,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.3175000000E+08,	.1770000000E+08,	.3670000000E+07,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.5760000000E+03,	.5150000000E+06,
	.3530000000E+05,	.2620000000E+09,	.1740000000E+09,	.4770000000E+08,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.2200000000E+04,	.1562000000E+04,
	.5750000000E+03,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
PDJ =	.1320000000E+09,	.7540000000E+03,	.4480000000E+03,	.1400000000E-14,
	.1000000000E-14,	.1000000000E-14,	.4450000000E+08,	.3390000000E+08,
	.2330000000E+08,	.1331000000E+07,	.1143000000E+07,	.3510000000E+06,
	.1949000000E+03,	.1532000000E+03,	.1314000000E+03,	.3920000000E+05,
	.3310000000E+05,	.2700000000E+05,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.3470000000E+01,	.2000000000E+01,	.7400000000E+00,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1370000000E+06,	.4110000000E+05,	.7520000000E+05,	.2710000000E+06,
	.2350000000E+06,	.1990000000E+05,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1380000000E+09,	.1384000000E+09,
	.9530000000E+08,	.4170000000E+09,	.2410000000E+07,	.5660000000E+08,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,	.1000000000E-14,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,	.0000000000E+00,
TRUS =	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,
	.0000000000E+00,	.0000000000E+00,	.7740000000E+09,	.0000000000E+00,
	.0000000000E+00,	.6530000000E+11,	.0000000000E+00,	.0000000000E+00,
	.4040000000E+02,	.0000000000E+00,	.0000000000E+00,	.2330000000E+05,
	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,	.0000000000E+00,
	.0000000000E+00,	.2700000000E+04,	.0000000000E+00,	.0000000000E+00,
	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,
	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,	.0000000000E+00,
	.0000000000E+00,	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,
	.1350000000E+06,	.0000000000E+00,	.0000000000E+00,	.2850000000E+07,
	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,	.0000000000E+00,
	.0000000000E+00,	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,
	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,
	.0000000000E+00,	.0000000000E+00,	.1130000000E+15,	.0000000000E+00,
	.0000000000E+00,	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,
	.1000000000E-14,	.0000000000E+00,	.0000000000E+00,	.1000000000E-14,

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

TRJ =

CDJS =

CDM =

I

.100000000E-14,	.100000000E-14,	.430000000E+09,	.400000000E+09,
.219[illegible]E+39,	.205000000E+03,	.130000000E+08,	.154000000E+08,
.039200000E+04,	.277800000E+04,	.245800000E+04,	.998000000E+06,
.695000000E+06,	.793000000E+05,	.100000000E-14,	.100000000E-14,
.100000000E-14,	.220000000E+02,	.100000000E-14,	.100000000E-14,
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.100000000E-14,	.100000000E-14,	.100000000E-14,	.100000000E-14,
.100000000E-14,	.100000000E-14,	.100000000E-14,	.100000000E-14,
.213300000E+07,	.213000000E+07,	.227900000E+07,	.397000000E+07,
.370000000E+07,	.117000000E+07,	.100000000E-14,	.100000000E-14,
.100000000E-14,	.100000000E-14,	.100000000E-14,	.100000000E-14,
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.100000000E-14,	.100000000E-14,	.239300000E+10,	.207600000E+10,
.175000000E+10,	.100000000E-14,	.100000000E-14,	.100000000E-14,
.100000000E-14,	.100000000E-14,	.100000000E-14,	.100000000E-14,
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.000000000E+00,	.000000000E+00,	.000000000E+00,	.000000000E+00,
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.000000000E+00,	.500000000E+00,	.000000000E+00,	.000000000E+00
+0			

NOTE =

$END

PART 5
BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY
1.0 BASIC MATERIALS DEMANDS AND SUPPLIES
(METRIC TONS)

MATERIAL		USED IN 1968 US	USED IN 1968 WORLD	PROJECTED DEMANDS IN YR 2000 US	PROJECTED DEMANDS IN YR 2000 WORLD	TOTAL RESOURCES US	TOTAL RESOURCES WORLD	CUMULATIVE DEMAND TO YR 2000 US	CUMULATIVE DEMAND TO YR 2000 WORLD
AL	H	.4200+07	.1000+08	.4000+08	.13270+09	.10000-14	.17000+13	.46700+09	.12000+10
	M	.0000	.0000	.3000+08	.75400+08	.00000	.00000	.33400+09	.15000+10
	L	.0000	.0000	.2000+07	.44870+08	.00000	.00000	.26200+09	.80000+09
ST	H	.1000-14	.1000-14	.6870+09	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.3494+09	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1722+09	.10000-14	.00000	.00000	.10000-14	.10000-14
CU	H	.2500+07	.7750+07	.1340+08	.48820+08	.77450+08	.67900+08	.11600+09	.48000+09
	M	.0000	.0000	.1170+08	.33960+08	.00000	.00000	.10100+09	.40000+09
	L	.0000	.0000	.1050+08	.23300+08	.00000	.00000	.87300+08	.31900+09
AB	H	.1000+05	.2600+06	.5510+06	.13310+07	.55600+11	.10000-14	.86000+07	.20600+08
	M	.0000	.0000	.5070+06	.11470+07	.00000	.00000	.79000+07	.18500+08
	L	.0000	.0000	.4520+06	.95400+06	.00000	.00000	.72000+07	.16400+08
PT	H	.1300+02	.4913+02	.7255+02	.19490+03	.40400+02	.56610+04	.20660+04	.30920+04
	M	.0000	.0000	.4360+02	.15520+03	.00000	.00000	.18560+04	.27780+04
	L	.0000	.0000	.3450+02	.13140+03	.00000	.00000	.16470+04	.24640+04
SMCO	H	.5400+04	.2000+05	.1380+05	.39200+05	.25300+05	.21800+08	.30400+06	.99900+06
	M	.0000	.0000	.1120+05	.33100+05	.00000	.00000	.27000+06	.89500+06
	L	.0000	.0000	.8440+04	.27300+05	.00000	.00000	.23600+06	.79000+06
GRAPH	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
BA	H	.3000+00	.1000-14	.1150+01	.31590+01	.27700+04	.25000+05	.19100+02	.22000+02
	M	.0000	.0000	.6900+00	.23500+01	.00000	.00000	.10000-14	.10000-14
	L	.1000+00	.0000	.2300+00	.73000+00	.00000	.00000	.10000-14	.10000-14

THE VALUE .1000E-14 INDICATES TO BE DETERMINED

PART 5

BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY

1.0 BASIC MATERIALS DEMANDS AND SUPPLIES

(METRIC TONS)

MATERIAL		USED IN 1968 US	USED IN 1968 WORLD	PROJECTED DEMANDS IN YR 2000 US	PROJECTED DEMANDS IN YR 2000 WORLD	TOTAL RESOURCES US	TOTAL RESOURCES WORLD	CUMULATIVE DEMAND TO YR 2001 US	CUMULATIVE DEMAND TO YR 2001 WORLD
AL	H	.4200+07	.1600+08	.4050+08	.13670+09	.10000-14	.17000+10	.46700+09	.12000+10
	M	.0000	.0000	.3300+08	.75470+08	.00000	.00000	.33400+09	.10000+10
	L	.0000	.0000	.2250+07	.44870+08	.00000	.00000	.26200+09	.60000+09
ST	H	.1000-14	.1000-14	.6875+19	.14000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.3434+19	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1722+19	.10000-14	.00000	.00000	.10000-14	.10000-14
CU	H	.2300+07	.7750+07	.1340+08	.43520+08	.77450+08	.47950+08	.11600+09	.48000+09
	M	.0000	.0000	.1175+08	.33760+08	.00000	.00000	.10100+09	.40000+09
	L	.0000	.0000	.1050+08	.23500+08	.00000	.00000	.87300+08	.31900+09
AB	H	.1000+05	.2600+05	.5510+05	.13310+07	.65500+11	.10000-14	.96000+07	.20600+08
	M	.0000	.0000	.5070+06	.11470+07	.00000	.00000	.79000+07	.18500+08
	L	.0000	.0000	.4520+06	.95200+05	.00000	.00000	.72000+07	.16400+08
PT	H	.1300+02	.4913+02	.7350+02	.17490+03	.40400+02	.56610+04	.20660+04	.30920+04
	M	.0000	.0000	.4360+02	.15520+03	.00000	.00000	.18560+04	.27780+04
	L	.0000	.0000	.3450+02	.13140+03	.00000	.00000	.16470+04	.24640+04
SMCO	H	.5400+04	.2000+05	.1350+05	.39200+05	.25300+05	.21800+08	.30400+06	.99900+06
	M	.0000	.0000	.1120+05	.37100+05	.00000	.00000	.27000+06	.89500+06
	L	.0000	.0000	.5440+04	.27000+05	.00000	.00000	.23600+06	.79070+06
GRAPH	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
BA	H	.3000+00	.1000-14	.1150+01	.33070+01	.27600+04	.25000+05	.19100+02	.22000+02
	M	.0000	.0000	.6900+00	.23500+01	.00000	.00000	.10000-14	.10000-14
	L	.1000+00	.0000	.2300+00	.73500+00	.00000	.00000	.10000-14	.10000-14

THE VALUE .1000E-14 INDICATES TO BE DETERMINED

I

PART 5

BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY

MATERIAL		USED IN 1968 US	USED IN 1968 WORLD	PROJECTED DEMANDS IN YR 2000 US	PROJECTED DEMANDS IN YR 2000 WORLD	TOTAL RESOURCES US	TOTAL RESOURCES WORLD	CUMULATIVE DEMAND TO YR 2 US	CUMULATIVE DEMAND TO YR 2 WORLD
CONCRT	H	.1000-14	.1000-14	.9144+11	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.3734+11	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1511+11	.10000-14	.00000	.00000	.10000-14	.10000-14
SI	H	.5193+02	.1000-14	.2545+05	.10000-14	.10000-14	.10000-14	.29670+04	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.26300+04	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.22930+04	.10000-14
TEFLON	H	.1000-14	.1000-14	.2424+11	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1764+11	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1400+11	.10000-14	.00000	.00000	.10000-14	.10000-14
KAPTON	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
W	H	.7360+04	.3320+05	.1000-14	.13700+05	.13600+06	.11930+08	.61600+06	.21830+07
	M	.0000	.0000	.1000-14	.91170+05	.00000	.00000	.55700+06	.21300+07
	L	.0000	.0000	.1000-14	.75220+05	.00000	.00000	.49800+06	.20780+07
MO	H	.2530+05	.6260+05	.9370+05	.27100+06	.23500+07	.49000+07	.16000+07	.39000+07
	M	.0000	.0000	.8740+05	.23570+06	.00000	.00000	.15000+07	.37000+07
	L	.0000	.0000	.6340+05	.19970+06	.00000	.00000	.14000+07	.11700+07
CERMIC	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
STST	H	.1000-14	.1000-14	.3175+05	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1775+08	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.8630+07	.10000-14	.00000	.00000	.10000-14	.10000-14

THE VALUE .1000E-14 INDICATES TO BE DETERMINED

PART 5

BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY

MATERIAL		USED IN 1968 US	USED IN 1968 WORLD	PROJECTED DEMANDS IN YR 2000 US	PROJECTED DEMANDS IN YR 2000 WORLD	TOTAL RESOURCES US	TOTAL RESOURCES WORLD	CUMULATIVE DEMAND TO YR 2000 US	CUMULATIVE DEMAND TO YR 2000 WORLD
INSU	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
INC	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
LOX	H	.1343+08	.3423+08	.6765+08	.18080+09	.11300+16	.10000-14	.62000+09	.23930+10
	M	.0000	.0000	.5150+08	.13680+09	.00000	.00000	.56600+09	.20750+10
	L	.0000	.0000	.3550+08	.95130+08	.00000	.00000	.51400+09	.17600+10
LH2	H	.5350+07	.1550+08	.1620+09	.41700+09	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1041+09	.24170+09	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.4770+08	.56600+09	.00000	.00000	.10000-14	.10000-14
RP1	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
C3H8	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14
HE	H	.1000-14	.1000-14	.2250+04	.10000-14	.55190+06	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1530+04	.10000-14	.23440+06	.00000	.10000-14	.10000-14
	L	.0000	.0000	.8750+03	.10000-14	.12500+06	.00000	.10000-14	.10000-14
N2	H	.1000-14	.1000-14	.1000-14	.10000-14	.10000-14	.10000-14	.10000-14	.10000-14
	M	.0000	.0000	.1000-14	.10000-14	.00+00	.00000	.10000-14	.10000-14
	L	.0000	.0000	.1000-14	.10000-14	.00000	.00000	.10000-14	.10000-14

THE VALUE .1000E-14 INDICATES TO BE DETERMINED

PART 5

2.3 ENERGY TO PRODUCE MATERIALS STATEMENT

RANK OF NON-CONSUMABLE MATERIALS USAGE BY WEIGHT

MATERIAL	AMOUNT (KG)	KWH/KG TO PRODUCE	TOTAL ENERGY TO PRODUCE	PAYBACK (YEARS)
AL	.1545+10	.2457+02	.4044+11	.5129+00
CONCRT	.1520+10	.7718+00	.1173+10	.1488-01
SILCON	.1749+08	.2457+02	.4298+09	.5452-02
MJD	.8787+07	.2457+02	.2159+09	.2738-02
TEFLON	.7865+07	.2457+02	.1938+09	.2458-02
GRAPH	.5345+07	.2457+02	.1475+09	.1822-02
KAPTON	.3871+07	.2457+02	.9512+08	.1206-02
CU	.3383+07	.1235+02	.4177+08	.5298-03
STEEL	.2521+07	.1369+01	.3515+07	.4459-04
SMCD	.1447+07	.2457+02	.3556+08	.4510-03
ELECT	.2295+05	.2457+02	.5641+07	.7156-04
RM	.2068+05	.2457+02	.5081+06	.6445-05
AG	.1170+05	.2457+02	.2875+06	.3646-05
GAAS	.7200+04	.2457+02	.1769+05	.2244-05
PT	.7042+04	.2457+02	.1730+06	.2195-05
W	.0000	.2457+02	.0000	.0000
MO	.0000	.2457+02	.0000	.0000
CERMIC	.0010	.2457+02	.0000	.0000
STST	.0000	.5543+03	.0000	.0000
INSU	.0010	.2457+02	.0000	.0000
INC	.0000	.2457+02	.0000	.0000
TOTAL			.4277+11	.5425+00

PART 5

2.0 ENERGY TO PRODUCE MATERIALS STATEMENT

RANK OF CONSUMABLE MATERIALS USAGE BY WEIGHT

MATERIAL	AMOUNT (KG)	KWH/KG TO PRODUCE	TOTAL ENERGY TO PRODUCE	PAYBACK (YEARS)
N2	.2872+10	.0000	.0000	.0000
LOX	.2641+10	.1154+01	.2542+10	.3224-01
RP1	.5384+09	.4000+01	.2154+10	.2732-01
LH2	.1473+09	.4926+02	92.91 ~~.6713+10~~	~~.8755-01~~ D
HE	.1000-11	.2457+02	.1000-11	.1000-11
D3H3	.0000	.2457+02	.0000	.0000
TOTAL			.1151+11	~~.1472+00~~
2.0 GRAND TOTAL			.5438+11	~~.1597+00~~

NOTE N2 ENERGY IS INCLUDED IN LOX

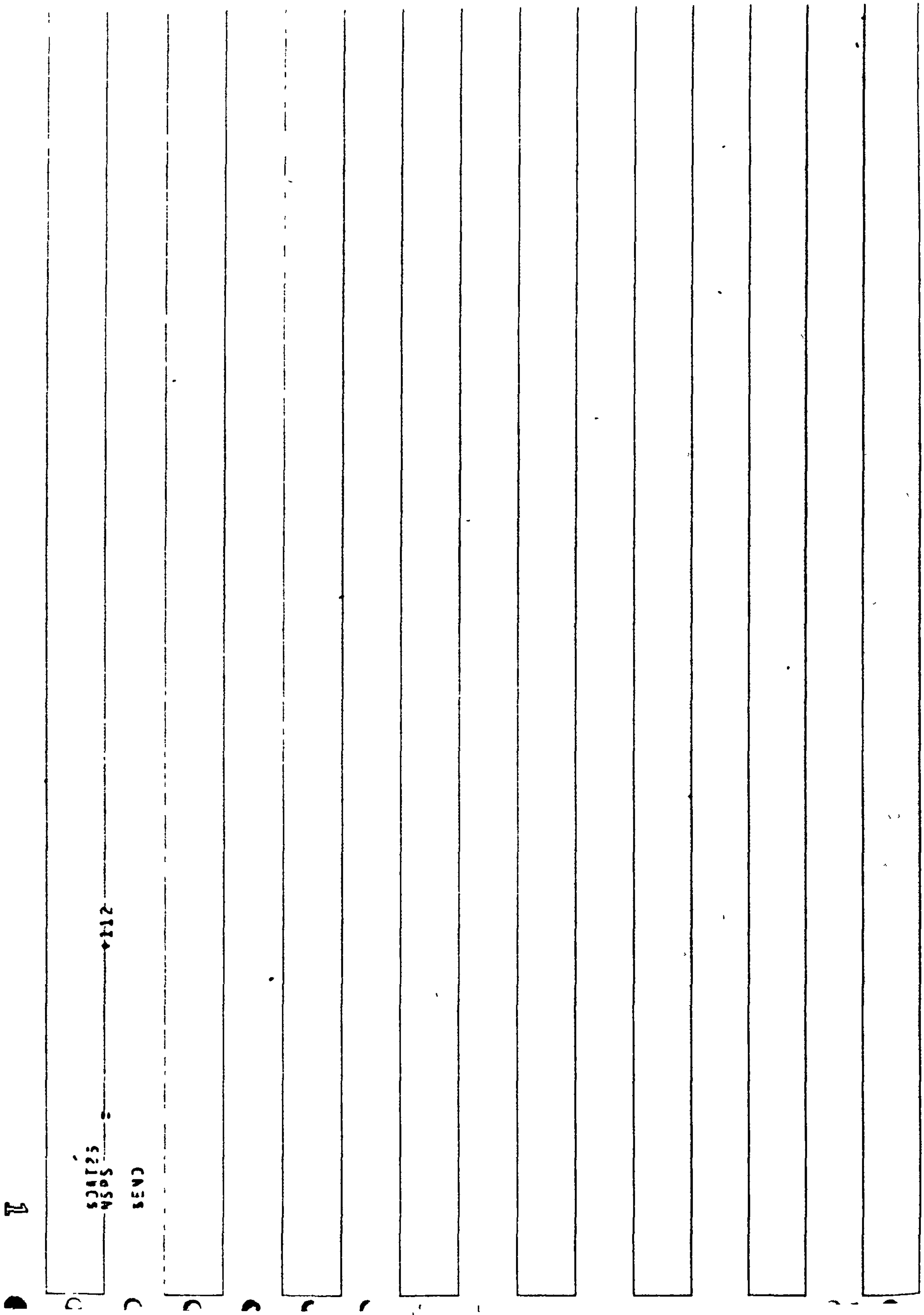
~~THE VALUE .1000-11 INDICATES TO BE DETERMINED~~

GRANDTOTAL PAYBACK INCLUDES .1 YEAR FOR GROUND GRADING FOR GROUND SYSTEM

~~TOTAL POWER OUTPUT = 7.884 X10+10 KWH~~

.1742
.5467
.716

.15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PART 5

BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY

3.0 SPS MATERIAL USAGE VS NATIONAL AND WORLD DEMANDS AND RESOURCES

MAT	AMOUNT M-TONS	PERCENT OF YEAR 2000 DEMAND FOR 1 SPS UNITED STATES			WORLD			PERCENT OF YEAR 2000 DEMAND-F UNITED STATES			
		HI	MED	LO	HI	MED	LO	HI	MED	LO	HI
AL	.155+07	.411+01	.549+01	.623+02	.161+01	.218+01	.367+01	.329+02	.439+02	.658+03	.129+02
SF	.253+04	.368-03	.726-03	.147-02	.100-14	.100-14	.100-14	.295-02	.581-02	.118-01	.100-14
CJ	.333+04	.263-01	.289-01	.319-01	.758-02	.995-02	.145-01	.238+00	.231+00	.255+00	.607-01
AS	.117+02	.239-02	.231-02	.259-02	.879-03	.107-02	.123-02	.157-01	.185-01	.207-01	.703-02
-> PT	.704+01	.398+01	.152+02	.204+02	.361+01	.431+01	.536+01	.799+02	.129+03	.163+03	.289+02
-> SMBD	.145+04	.105+02	.129+02	.171+02	.369+01	.437+01	.536+01	.659+02	.103+03	.137+03	.295+02
GRAPH	.534+04	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14
GA	.723+01	.526+03	.134+04	.313+04	.212+03	.351+03	.103+04	.501+04	.835+04	.250+05	.169+04
CONCRT	.152+07	.187-02	.410-02	.944-02	.100-14	.100-14	.100-14	.149-01	.328-01	.755-01	.100-14
SI	.175+05	.689+02	.100-14	.100-14	.100-14	.100-14	.100-14	.551+03	.100-14	.100-14	.100-14
TEFLON	.789+04	.325-04	.447-04	.563-04	.100-14	.100-14	.100-14	.260-03	.358-03	.451-03	.100-14
KAPTON	.337+04	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14

NOTE: THE VALUE .100-11 INDICATES THE AMOUNT OF MATERIAL IS TO BE DETERMINED
THE VALUE .100-14 INDICATES THE DEMAND AND RESOURCE INFORMATION IS TO BE DETERMINED

PART 5

BASIC MATERIALS DEMANDS,SUPPLIES, AND AVAILABILITY

3.0 SPS MATERIAL USAGE VS NATIONAL AND WORLD DEMANDS AND RESOURCES

MAT	AMOUNT M-TONS	PERCENT OF YEAR 2000 DEMAND FOR 1 SPS UNITED STATES			WORLD			PERCENT OF YEAR 2000 DEMAND FO UNITED STATES			
		HI	MED	LO	HI	MED	LO	HI	MED	LO	HI
W	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
MO	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
CERMIC	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
SISI	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
INSU	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
IND	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
LOX	.224+07	.332+01	.435+01	.635+01	.124+01	.157+01	.233+01	.265+02	.348+02	.508+02	.992+01
LH2	.140+06	.866-01	.135+00	.294+00	.336-01	.562-01	.211+00	.693+00	.108+01	.235+01	.269+00
RP1	.533+06	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14
C3H8	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
HE	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11
N2	.230+07	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14

NOTE: THE VALUE .100-11 INDICATES THE AMOUNT OF MATERIAL IS TO BE DETERMINED
THE VALUE .100-14 INDICATES THE DEMAND AND RESOURCE INFORMATION IS TO BE DETERMINED

PART 5

BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY

3.0 SPS MATERIAL USAGE VS NATIONAL AND WORLD DEMANDS AND RESOURCES

MAT	AMOUNT M-TONS	PERCENT RESERVES FOR 1 SPS US	FOR 1 SPS WORLD	FOR 3 SPS US	FOR 3 SPS WORLD	PERCENT CUMULATIVE DEMAND FOR 112 SPS UNITED STATES HI	UNITED STATES MED	UNITED STATES LO	WORLD HI	WORLD MED	WORLD LO
AL	.155+07	.100-14	.127+00	.100-14	.101+01	.453+02	.552+02	.724+02	.154+02	.184+02	.230+02
ST	.253+04	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14
CU	.333+04	.437-02	.121-01	.351-01	.970-01	.327+00	.375+00	.434+00	.789-01	.947-01	.119+00
AG	.117+02	.180-07	.100-14	.144-05	.100-14	.152-01	.166-01	.182-01	.636-02	.708-02	.799-02
PT	.704+01	.179+02	.105+00	.139+03	.845+00	.762+02	.425+02	.479+02	.255+02	.284+02	.320+02
SMCO	.145+04	.572+01	.554-02	.458+02	.531-01	.537+02	.500+02	.467+02	.162+02	.161+02	.205+02
GRAPH	.534+04	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14
GA	.725+01	.267+00	.288-01	.213+01	.230+00	.422+04	.100-14	.100-14	.367+04	.100-14	.100-14
CONCRT	.152+07	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5
SI	.175+05	.100-14	.100-14	.100-14	.100-14	.460+05	.745+05	.854+05	.100-14	.100-14	.100-14
TEFLON	.789+04	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5
KAPTON	.337+04	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5	.100-1~~4~~5

NOTE: THE VALUE .100-11 INDICATES THE AMOUNT OF MATERIAL IS TO BE DETERMINED
THE VALUE .100-14 INDICATES THE DEMAND AND RESOURCE INFORMATION IS TO BE DETERMINED

THE VALUE .100-10 INDICATES NOT APPLICABLE

PART 5

BASIC MATERIALS DEMANDS, SUPPLIES, AND AVAILABILITY

3.0 SPS MATERIAL USAGE VS NATIONAL AND WORLD DEMANDS AND RESOURCES

MAT	AMOUNT M-TONS	PERCENT RESERVES FOR 1 SPS US	FOR 1 SPS WORLD	FOR 5 SPS US	FOR 5 SPS WORLD	PERCENT CUMULATIVE-DEMAND FOR 112 SPS UNITED STATES HI	UNITED STATES MED	UNITED STATES LO	WORLD HI	WORLD MED	WORLD LO
W	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
MO	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
CERMIC	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
SISI	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
INSU	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
INC	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
LOX	.224+07	~~.158-26~~ .100 10-16	.100-14	~~.158-05~~ .100-10-5	.100-14	.405+02	.444+02	.468+02	.105+02	.121+02	.143+02
LH2	.149+06	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14
RP1	.533+06	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14
C3H8	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
HE	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11	.100-11
N2	.253+07	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14	.100-14

NOTE: THE VALUE .100-11 INDICATES THE AMOUNT OF MATERIAL IS TO BE DETERMINED
THE VALUE .100-14 INDICATES THE DEMAND AND RESOURCE INFORMATION IS TO BE DETERMINED

PART 1
EXECUTIVE SUMMARY

1.0 SOLAR POWER SATELLITE

COLUMN/CABLE STRUCTURE DESIGN
TOTAL POWER OUTPUT = 7.884 X10*10 KWH
MPTS MASS (MT) .1574+05
SECS MASS (MT) .3850+05
TOTAL SPS MASS (MT) = .5425+05
RECTENNA MASS (.3155+07
OTHER MASS (MT).7574+04

TOTAL SYSTEM MASS (MT) = .3217+07

NOMINAL - MPTS DESIGN CASE
NOMINAL SECS BLANKET MASS OF 400.00 GM/SQ METER
NOMINAL SECS BLANKET AREA OF 71.592 X10*3 SQ METERS

2.0 TRANSPORTATION SYSTEM

2-STAGE BALLISTIC HLLV FOR A 454. MT PAYLOAD
CAPE LAUNCH TO INCLINED ORBIT, 300. FLIGHT LIFETIME
LOX/RP-1 FUELED STAGE 1, LOX/LH2 FUELED STAGE 2
TOTAL INERT WEIGHT (MT) = .7338+03
TOTAL FUEL WEIGHT/FLIGHT (MT) = .6376+04

2-1/2 STAGE COTV FOR 250. MT PAYLOAD
CAPE LAUNCH TO INCLINED ORBIT, 30. FLIGHT LIFETIME
LOX/LH2 FUELED, NOMINAL CASE
TOTAL INERT WEIGHT (MT) = .4400+02
TOTAL FUEL WEIGH/FLIGH (MT) = .6180+03

PLV MODIFIED SHUTTLE FOR A 75. PASSENGER PAYLOAD
100. FLIGHT LIFETIME
LOX/LH2 FUELED EXTERNAL TANK
LOX/RP1 FUELED LIQUID ROCKET BOOSTER
TOTAL INERT WEIGHT (MT) = .1560+03
TOTAL FUEL WEIGHT/FLIGHT (MT) = .1892+04

2-1/2 STAGE POTV FOR A 200. PASSENGER PAYLOAD
30. FLIGHT LIFETIME
LOX/LH2 FUELED, NOMINAL CASE
TOTAL INERT WEIGHT (MT) = .3500+02
TOTAL FUEL WEIGHT/FLIGHT (MT) = .6180+03

PART 1
EXECUTIVE SUMMARY
(CONTINUED)

3.0 CONSTRUCTION SYSTEM

NOMINAL SPS ASSEMBLY TIME = 1 YEAR
ASSEMBLY RATE (SPS/YEAR)
MINIMUM = .5
MAXIMUM = 8
COMPLETE CONSTRUCTION IN GEO
FINAL NO. SPS IN ORBIT = 112
SPS MAINTENANCE (MT) = TBD

4.0 ENERGY PAYBACK (YEARS)

	NON-CONS	CONSUM	TOTAL
MPTS	.3393-02	.0000	.3393-02
SECS	.1232-01	.0000	.1232-01
GROUND	.5239+00	.0000	.5239+00
OTHER	.2515-02	.1472+00	.1498+00
TOTAL	.5424+00	.1472+00	.7895+00

5.0 MATERIALS EXCEEDING 20 PERCENT
OF NATIONAL AND WORLD DEMAND

PERCENT ANNUAL DEMAND FOR 1 SPS CONSTRUCTED

MATERIAL	HI/MED/LO	US/WORLD	PERCENT
AL	LO	US	.323+02
PT	LO	US	.234+02
GA	LO	US	.315+04
GA	LO	WORLD	.103+04
SI	HI	US	.589+02

to be worked out.

5.0 MATERIALS EXCEEDING 20 PERCENT
OF NATIONAL AND WORLD DEMAND

PERCENT ANNUAL DEMAND FOR 8 SPS CONSTRUCTED

MATERIAL	HI/MED/LO	US/WORLD	PERCENT
AL	LO	US	.555+03
AL	LO	WORLD	.294+02
PT	LO	US	.153+03
PT	LO	WORLD	.429+02
SMCO	LO	US	.137+03
SMCO	LO	WORLD	.429+02
GA	LO	US	.250+05
GA	LO	WORLD	.375+04
SI	HI	US	.552+07
LOX	LO	US	.538+02

5.0 MATERIALS EXCEEDING 2 PERCENT
OF NATIONAL AND WORLD RESERVES

PERCENT RESERVES FOR 1 SPS CONSTRUCTED

MATERIAL	US/WORLD	PERCENT
PT	US	.174+02
SMCO	US	.572+01

5.0 MATERIALS EXCEEDING 2 PERCENT
OF NATIONAL AND WORLD RESERVES

PERCENT RESERVES FOR 3 SPS CONSTRUCTED

MATERIAL	US/WORLD	PERCENT
PT	US	.139+03
SMCO	US	.453+02

54	JS	.213+01

FIN

```
RUNID: DSLKI    ACCT: 3377-2999-C    PROJECT: EZ-L79874
  1- MOUNT <SAVE> 5/1 OUT -1 DSLKI
     LOAD K02471 5/2 IN -1 DSLKI
  1 K13330
TIME:     TOTAL: 00:01:05.736    CHARGE: 00:01:05.736
          CAU:   00:00:15.624    I/O:    00:00:32.597
          CC/ER: 00:00:17.518    WAIT:   00:00:00.000
SRC:      PS -- 34476616          ES -- 12348P1
IMAGES  READ:   445        PAGES:  124
START:    05:20:15 JAN 03,1977    FIN:  05:24:31 JAN 03,1977
```

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

IX. PROGRAM DEVELOPMENT PLAN

Harold Benson
Systems Evaluation

A. NASA/ERDA SPS CONCEPT DEVELOPMENT AND EVALUATION PROGRAM PLAN 1977-1980

A joint plan has been developed between NASA and ERDA. The basic objectives of this plan are to develop sufficient understanding of the technical requirements, economic practicability, and social and environmental acceptability of the satellite power system concept to enable a preliminary program continuation decision to be made in calender year 1979 and a final decision to be made in calendar year 1980 to either continue with the program at a level of effort to be determined or to phase it out. The basic elements of this plan are studies relating to: (1). Systems Definition (2). Space Related Technology (3). Environmental Factors (4). Impact and Benefits (5). Comparative Evaluations. The major milestones, schedule, and funding levels of these activities are shown in figure IX-A-1. NASA will manage the Systems Definition and Space Related Technology Studies and ERDA will have responsibility of Environmental Factors, Impact and Benefits, and Comparative Evaluations Studies.

At the Johnson Space Center, the Systems Definition Studies will be the primary funded activity in support of the Space Solar Power concept. Additional activities will include transportation, operations, and selected environmental studies. It is recognized that a strong interaction is required with these studies as well as the studies primarily managed by ERDA and other elements of NASA. Figure IX-A-2 is an organizational structure of how JSC will manage Solar Power Satellite Concept Evaluation. Key individual contacts are identified within this organizational chart. The JSC milestones will duplicate the joint NASA/ERDA plan and precede the joint plan by several months. The following dates will be the milestones for the four major program elements.

Preferred Concept(s) Selection	October 1978
Preliminary Program Recommendations	May 1979
Updated Program Recommendations	January 1980
Final Program Recommendations	June 1980

NASA-ERDA PROGRAM DEFINITION PLAN

(CONCEPT EVALUATION)

TASK DESCRIPTION	FY77	FY78	FY79	FY80	
	SYSTEM CONCEPTS DEFINED	PREFERRED CONCEPTS SELECTED	PRELIMINARY PROGRAM CONTINUATION	FINAL PROGRAM CONTINUATION DECISION	TOTAL FUNDING (MILLIONS)
SYSTEMS DEFINITION STUDIES (2)	$1.8	$1.7	$1.3	$ .8	$5.6
SPACE RELATED TECHNOLOGY	$ .7	$1.8	$1.2	$ .8	$4.5
ENVIRONMENTAL FACTORS	$ .6	$1.7	$2.0	$1.7	$6.0
IMPACT AND BENEFITS	$ .2	$ .5	$ .5	$ .3	$1.5
COMPARATIVE EVALUATIONS	$ .1	$ .4	$ .8	$ .6	$1.9
TOTAL BY YEAR	$3.4	$6.1	$5.8	$4.2	$19.5

FIGURE IX-A-1

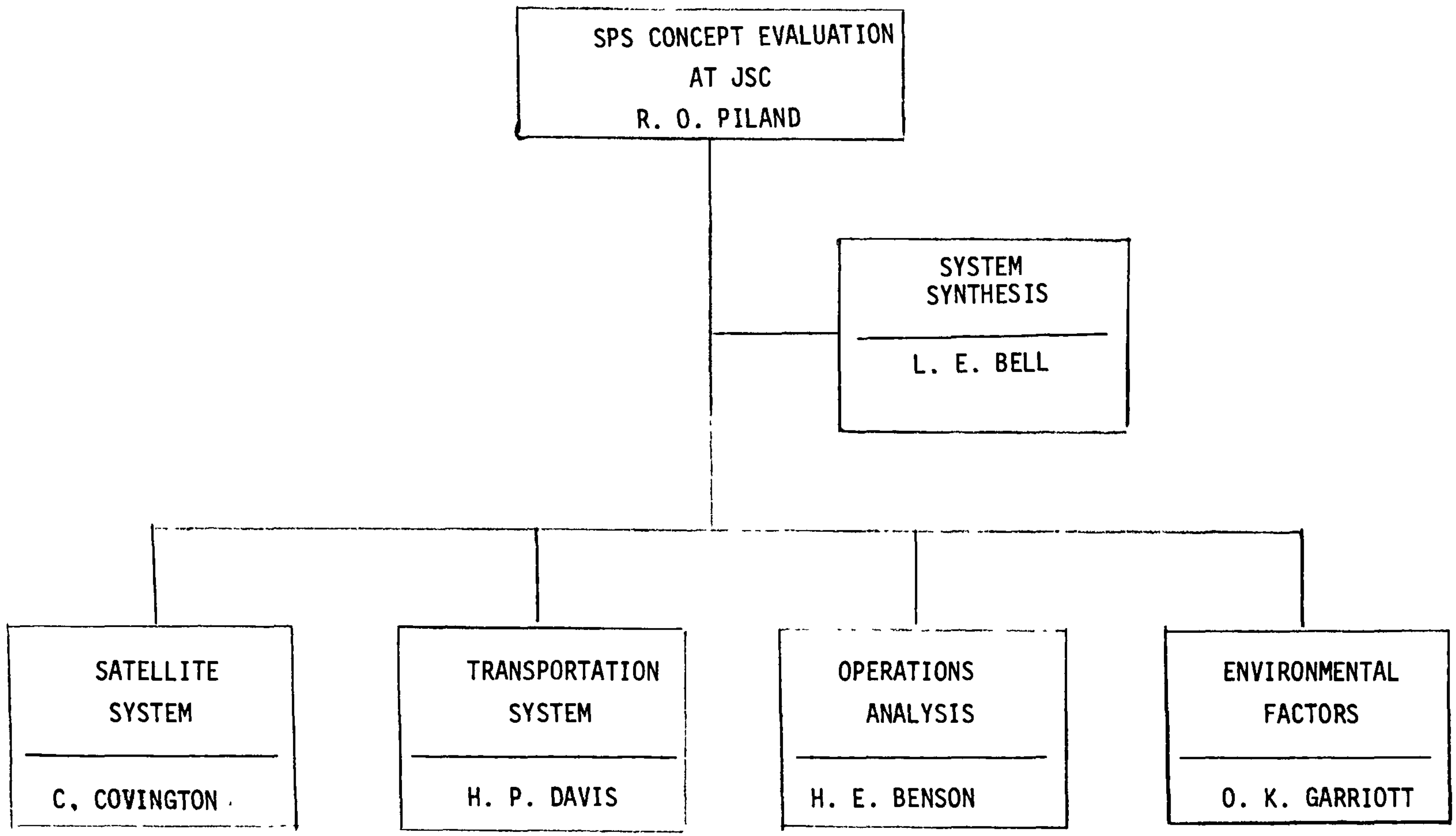

SPS CONCEPT EVALUATION
AT JSC
R. O. PILAND
SYSTEM
SYNTHESIS
L. E. BELL
SATELLITE
SYSTEM
C. COVINGTON
TRANSPORTATION
SYSTEM
H. P. DAVIS
OPERATIONS
ANALYSIS
H. E. BENSON
ENVIRONMENTAL
FACTORS
O. K. GARRIOTT

FIGURE IX-A-2

IX. PROGRAM DEVELOPMENT PLAN

B. TECHNOLOGY ADVANCEMENT PLAN 1980-1987

1. <u>Technology Advancement Requirements</u>

L. E. Livingston
Spacecraft Design Division

Previous SPS studies have produced a wide variety of configurational approaches, but have had at least one conclusion in common: although the program appears feasible, substantial advances will be necessary in many technical areas before an SPS program can be initiated with a reasonable degree of confidence.

As a follow-on to JSC 11568 (the "green book"), a three-month effort was initiated to establish (1) a comprehensive list of these critical technology areas and (2) a preliminary definition of an integrated technology advancement program, the purpose of which would be to resolve the critical technology issues to the extent necessary for a rational decision to initiate an SPS development program. The results of this effort have been reported as "Preliminary Assessment of Technology Advancement Requirements for Space Solar Power", March 1977 (JSC-12702), which should be consulted for details. The following is a summary of the report.

For this study, "critical technology area" was defined as any technical problem that must be resolved prior to an SPS program implementation decision. The definition was intentionally broad and encompassed such questions as the following:

1. Feasibility of system and component design concepts
2. Component performance and efficiency
3. Component producibility in required quantities
4. Properties of materials
5. Understanding of natural phenomena
6. Verification of analyses

Development of the SPS itself was not included in this definition. Where the state of the art was such that a problem was reasonably assured of solution during a normal development program, that problem was not considered a "critical technology area". However, the existence or anticipated existence of a solution to a problem did not rule out the inclusion in the program of other possible solutions offering significant potential improvements in weight, cost, etc.

The general guidelines used in JSC-11568 were adopted for this study. In addition, the following guidelines were used:

1. Scenario B of the in-house study will be assumed (112 10-GW satellites placed in operation during the period 1995 to 2025).

2. Photovoltaic and thermal energy conversion systems will be given equal consideration.

3. The transportation system and depot functions of the construction base will not be considered.

4. The technology advancement program will span the period 1979 to 1987. Data to support an implementation decision for the technology advancement program must be available by December 1978. Data from this program to support an SPS program implementation decision must be available by December 1986.

Critical technology areas have been identified for most of the subsystems and disciplines within the scope of this study. In a few cases, little or no work has been done because of shuttle support requirements. These include thermal energy conversion (brief discussion) and attitude control and antenna pointing (no discussion). It is planned that these omissions be remedied as soon as manpower becomes available.

The critical areas identified during this study are listed in table IX-B-1 by discipline. In several cases, a similar or identical problem was mentioned in connection with more than one discipline. These duplications or partial duplications are cross-referenced in the table. The listing within each discipline follows the order of the discussions in the detailed report and does not necessarily reflect any ranking in terms of importance, criticality, etc.

The test programs proposed to resolve these problems are summarized in schedule form in figure IX-B-1. As in table IX-B-1, the order follows that of the detailed report.

The estimated cost of all proposed tests is summarized in figure IX-B-2 on an annual basis. Where more than one discipline proposed substantially identical tests, the lower cost estimate was omitted from the compilation; there were very few such duplications. In each case, the cost was assumed to be uniformly distributed over the schedule given for that test. Cost estimates could not be provided for thermal energy conversion, antenna pointing, and attitude control because of priority shuttle support commitments. All other test requirements are included.

Figure IX-B-2 categorizes cost estimates in two ways. The first distinguishes between (1) ground tests, (2) flight tests of components and subsystems, and (3) integrated system flight tests, including those tests which would logically be incorporated into an integrated program, whether or not such incorporation was necessary to the individual test. The second categorization distinguishes between shuttle and construction base supported test activities.

"Component and subsystem tests" is intended to encompass all tests not directly applicable to or appropriately included in an integrated systems test which is part of the technology advancement program. Specifically, it is taken here to include full-scale structural fabrication tests, the products of which would be of little use in a sub-scale systems test configuration. This item represents most of the cost in the construction base subsystem test category.

The total of all cost estimates is $754 million. The two major contributors are construction (67%) and structures (19%), due primarily to the impracticality of ground testing and the limited validity of subscale construction operations. Note, however, that the solar cell development program proposes to make extensive use of other currently planned work for both terrestrial and space applications; otherwise, solar cell development costs could have been much higher.

Thermal cycle conversion, for which estimates were not available, will require substantial efforts. Some part of the attitude control problem is included under structure, but not all of it. Hence, it is not unreasonable to anticipate a total cost of one billion dollars.

TABLE IX-B-1 - CRITICAL TECHNOLOGY AREAS

Note: Where an identical or similar area was identified under more than one discipline, the other disciplines are cross-referenced in parentheses.

A. <u>Photovoltaic Energy Conversion</u>

Solar cell blankets:
- Thermal cycling
- Electron/proton and ultraviolet radiation effects
- Fabrication techniques

Solar concentrators (reflectors): (B, M)
- Radiation effects
- Micrometeoroid effects

Electrical and mechanical performance of very large arrays
High voltage/plasma interactions (M, N)

B. <u>Thermal Energy Conversion</u>

Radiator fabrication techniques (T)
Fluid-tight joints
Thin-film concentrator materials (A, M)
High-temperature heat exchanger materials
Superconducting generators and power cables
Leak detection and repair

C. <u>Microwave System Analysis</u>

Ionosphere power density limits (D)
Microwave generator development (E)
Phase control techniques (G)
Slotted waveguide antenna designs (F, M)
Rectenna development (H)

D. <u>Microwave System</u>

Transmission frequency
Ionosphere power density limits (C)
Heat dissipation from microwave generators and antenna (L)
Transmitting antenna construction and operation
Interfaces with transmitting antenna
Microwave system-level problems
Microwave effects on other areas

TABLE IX-B-1 - CRITICAL TECHNOLOGY AREAS (CONTINUED)

E. Microwave Generation (C)

Efficiency
Reliability
Low noise
Low weight
Stability

F. Antenna Subarrays

Efficiency
Power level effects
Manufacturing techniques (C, M)

G. Phase Control (C)

Phase noise
Interference rejection
High-power phase stability
Atmospheric phase perturbation
Phase reference/control
Phase control accuracy
Fiber optics

H. Microwave Reception (C)

Collection efficiency
RF-DC conversion efficiency
Factors influencing rectenna size
Low-cost rectenna elements
Sensitivity to beam power density and grid loads
Pilot beam interfaces
Maintenance

J. Distribution Grid Interface

(No critical technology areas)

K. Structural Design

Solar collector structure/attitude control interactions (Q)
Antenna stiffness/pointing accuracy/attitude control interactions (P,
Antenna subarray chassis/thermal control (L)
Structural elements for space construction (T)
Numerical characterization of SPS structural performance
Similitude modeling for subscale testing
Eclipse response (L)

TABLE IX-B-1 - CRITICAL TECHNOLOGY AREAS (CONTINUED)

L. Thermal Control

Microwave generator thermal design (D)
MPTS thermal control (D, K)
Thermal design of rotary joint
Thermal control of power distribution system
Transient response of structure during eclipse (K)

M. Materials

Availability of graphite for SPS construction
Graphite composite lifetime
Graphite composite cables
Tension cable lifetime
Application of vapor-deposited coatings in orbit
Solar concentrator film lifetime (A, B)
Thermal control surface lifetime
Joining techniques and properties (T)
Waveguide materials and fabrication techniques (C, F)
Electrostatic charging phenomena (A, N)

N. Power Distribution

Thin sheet conductors
Power bus insulation (A, M)
Power switching
System verification

O. Communications and Instrumentation

(No critical technology areas)

P. Antenna Pointing Control (K)

(No data available)

Q. Stabilization and Control (K)

(No data available)

R. Propulsion and Reaction Control

MPD arc-jet thruster
100-cm ion thruster

TABLE IX-B-1 - CRITICAL TECHNOLOGY AREAS (CONTINUED)

S. Rotary Joint

Slip rings and brushes

T. Orbital Construction

Automatic fabrication of elemental truss (K, M)
Assembly of elemental trusses into long truss (K)
Large space radiator construction (B)
Deployment and attachment of solar cell blankets
Deployment and attachment of planar concentrator membrane
Deployment and attachment of contoured concentrator membrane
Space installation of power distribution cables
Handling and berthing large modules
Integrity verification of space-fabricated structures
Assembly of jigs and fixtures for orbital construction
Fabrication of large pressure vessel in orbit

FIGURE IX-B-1 - TEST PROGRAM SCHEDULE SUMMARY

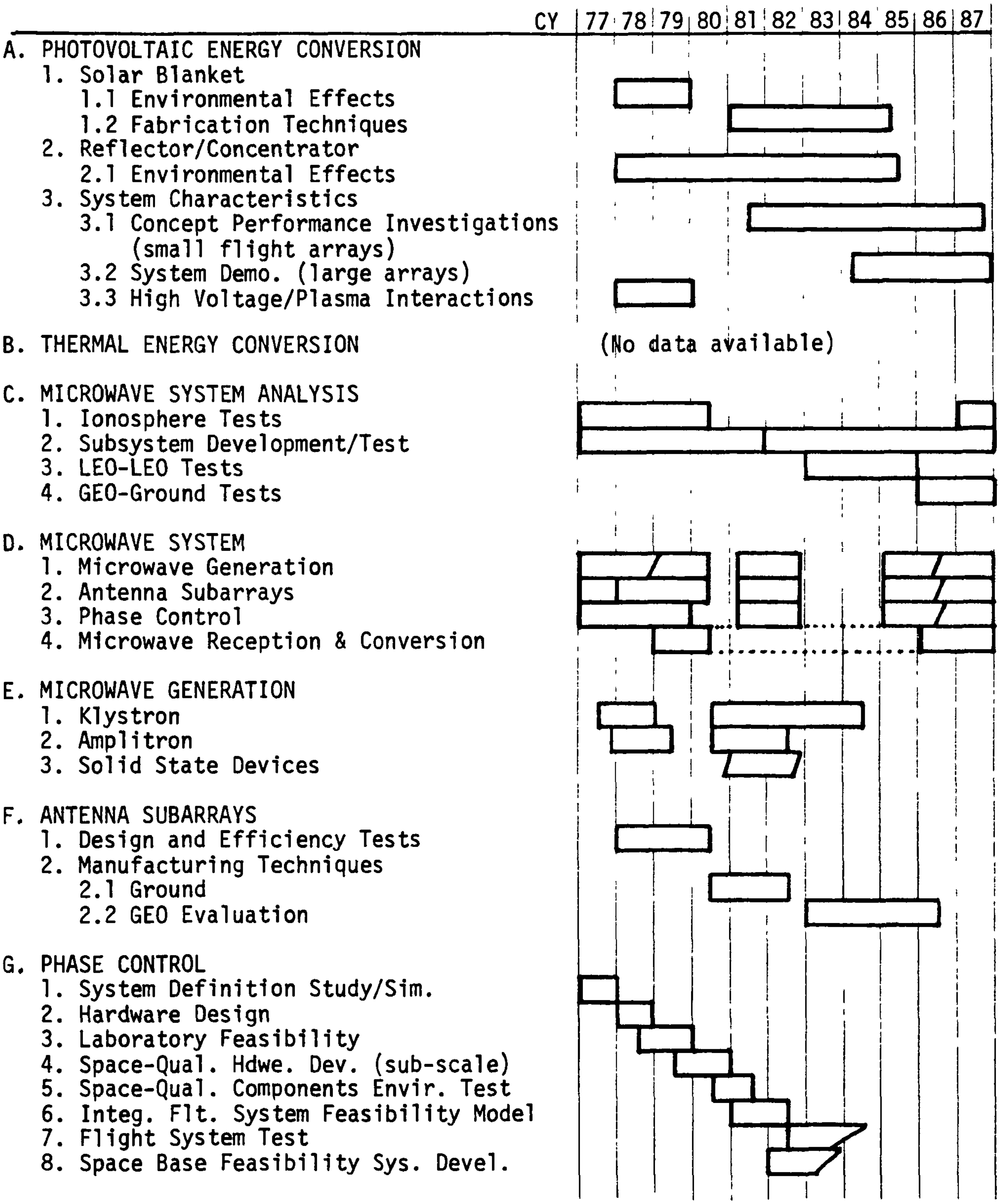
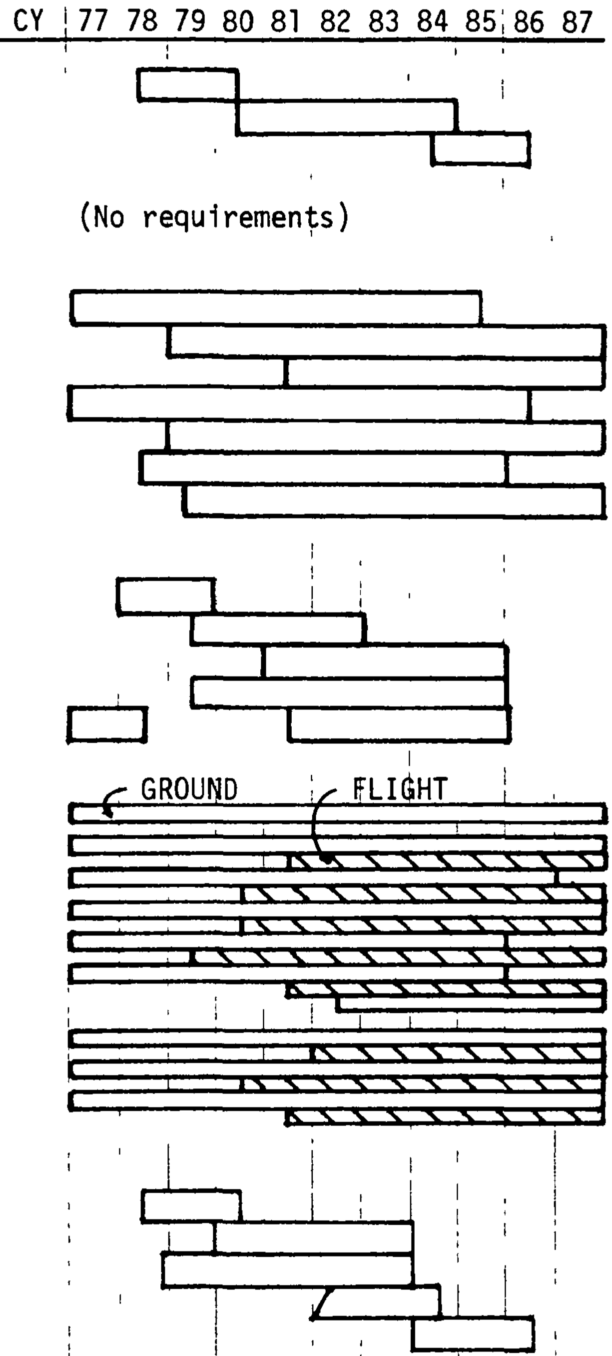


FIGURE IX-B-1 - TEST PROGRAM SCHEDULE SUMMARY (CONTINUED)



H. MICROWAVE RECEPTION & CONVERSION
1. Rectenna Studies
2. Rectenna Development
3. Rectenna Integration

J. DISTRIBUTION GRID INTERFACE (No requirements)

K. STRUCTURAL DESIGN
1. Solar Coll./Att. Cont. Interaction
2. Antenna/Pointing/Att. Cont. Inter.
3. Subarray Chassis/Thermal Control
4. Structural Elements
5. Structural Performance Analysis
6. Similitude Modeling
7. Eclipse Response

L. THERMAL CONTROL
1. Microwave Generator
2. Microwave Antenna
3. Rotary Joint
4. Power Distribution
5. Eclipse Response

M. MATERIALS
1. Graphite Availability
2. Graphite Composite Lifetime
3. Graphite Composite Cables
4. Tension Tie Cables
5. Vapor-Deposited Coatings
6. Solar Reflector Films
7. Thermal Control Surfaces
8. Joining Techniques/Properties
9. Waveguide Matl. & Fab. Techniques
10. Electrostatic Charging

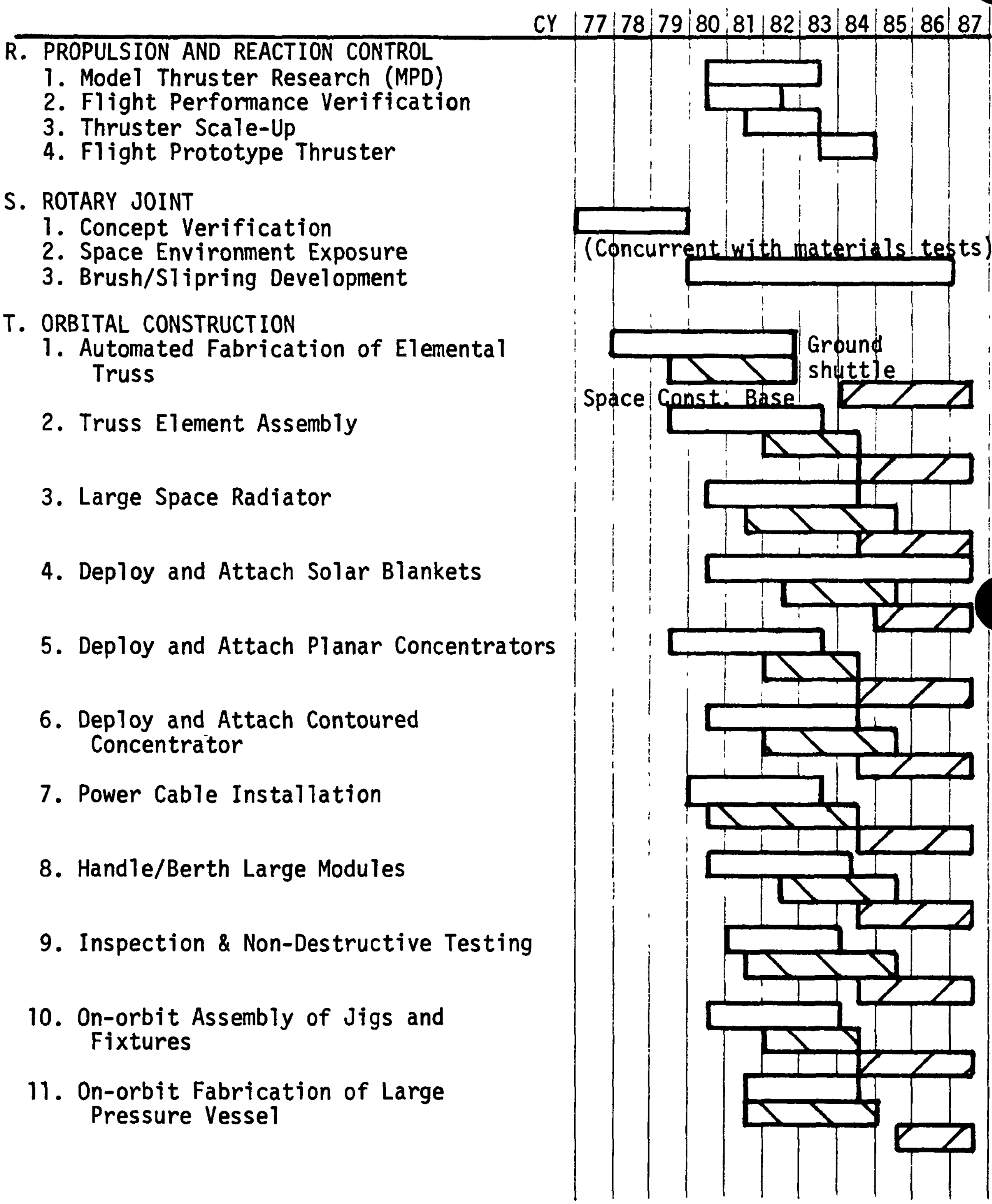
N. POWER DISTRIBUTION
1. Conductor Development
2. Insulator Development
3. Power Controllers
4. Technology Breadboard
5. Flight Demonstration

O. COMMUNICATIONS/INSTRUMENTATION (No requirements)

P. ANTENNA POINTING CONTROL (No data available)

Q. STABILIZATION AND CONTROL (No data available)

FIGURE IX-B-1 - TEST PROGRAM SCHEDULE SUMMARY (CONTINUED)



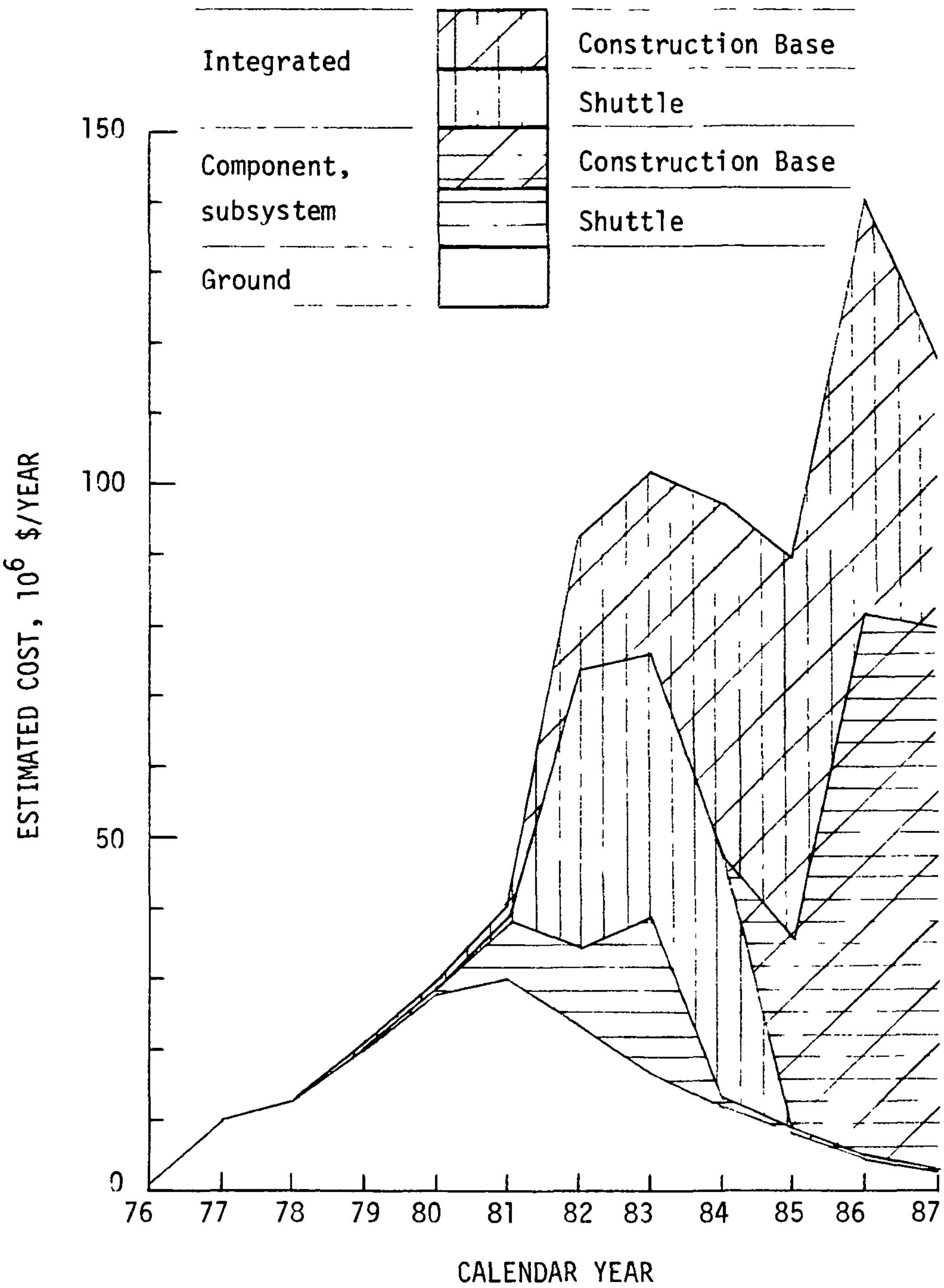


FIGURE IX-B-2 - ESTIMATED ANNUAL COST OF TEST PROCEDURES

R. H. Dietz
Tracking and Communications
Development Division

IX. PROGRAM DEVELOPMENT PLAN

B. Technology Advancement Plan 1980-1987

2. Ground Activities

Microwave system testing, a scenario for ground testing of the SPS microwave system has been developed which expands on the work documented in JSC-12702, "Preliminary Assessment of Technology Advancement Requirements for Space Solar Power," dated March 1977, and discussed in the above sections.

Groundrules established were:

(1) System-level tests are required on the microwave system.

(2) Ground tests will be performed in preference to space tests, where valid results can be obtained, recognizing that physical size will be a limiting factor.

(3) Existing facilities will be used insofar as practical.

(4) System tests will be phased to take advantage of the microwave component development tests, both from the standpoint of test results and equipment availability.

With the above groundrules in mind, a group of ground tests have been formulated which are system-level tests of the MW system and which utilize, as much as possible, existing facilities. The following facilities have been considered:

a. Anechoic Chamber - used for testing large antennas, and antennas on large objects. Antenna patterns, antenna efficiencies, and electromagnetic interference measurements can be made.

The anechoic chamber is configured and designed as a modified flared-waveguide horn of all metal construction with RF absorbing material on the inner surfaces. The chamber has a clear working height and width of 50 feet and an overall length of 150 feet. The electromagnetic shielding is a minimum of -100 dB from 10 KHz to 10,000 MHz.

b. Antenna Test Range - used for making measurements of antenna radiation patterns. This facility is a combination ground-reflecting/free-space antenna range 1000 or 2000 feet long. The receiver/transmitter heights are 35 feet and 0-75 feet. It also consists of a heavy-duty 2-axis positioner capable of supporting test objects up to 20,000 pounds. All motions and data control or readout are performed remotely from a central control room. The frequency range covered by the facility is 200 MHz to 26,500 MHz.

c. Microwave and Laser Laboratory - used for checking microwave systems, laser/electro-optical systems, component subsystems, and techniques. Complete evaluation of visible to infrared laser systems as

well as active and passive Ku-band systems can be conducted. A mechanically stable platform for very accurate laser transmitter and receiver work is provided together with a cylindrical vacuum tube 80m long by 4m in diameter. Temperature over the entire length of the tube may be controlled within ± 2°F.

d. Thermal-Vacuum Test Chamber A - used for manned and unmanned development and qualification testing of complete spacecraft or major system hardware in high-fidelity simulated thermal-vacuum space environments. The 19.8m diameter x 36.6m high stainless steel vacuum vessel provides a working volume within a 90°K heat sink shroud of approximately 16.8m x 27.4m.

After component development of SPS MW System laboratory models, such as the antenna subarray/waveguides, microwave generators, and the phase control system, early tests should be performed which integrate these elements into a portion or part of the MW system. Total integrated system performance should be determined to the maximum extent possible. A scenario of possible tests on the MW system is described below.

Measurement of Subarray Efficiencies - antenna/subarray/waveguide efficiencies can be measured utilizing the antenna range and anechoic chamber. RF radiation would be at low power from a 10m x 10m subarray. Radiated energy would be collected through a cross-section of the solid angle extended by the MW beam. The phase control system would not be turned on.

Optimum gap spacing between waveguides/subarray elements can be determined by adjusting waveguide spacing, and element spacing within the 10m x 10m subarray and making pattern/efficiency measurements.

Power Beam/Phase Control Shielding - a critical area requiring early testing is the isolation between the relatively weak uplink phase control signal and the strong downlink power beam. Assuming for test purposes that phase control is to each MW generator; two MW generators, two conjugation circuits, and the ground phase control circuitry would be required. Spacing of each MW generator, together with its attendant conjugation circuits could be varied and system isolation measurements could be made. RF shielding between received and transmitted signals may be required as well as signal data processing schemes. Tests would be conducted in the anechoic chamber.

Effectiveness of Phase Control System - using a 10m x 10m subarray and appropriate phase control drive signal ports, pattern measurements can be made which will determine effectiveness of the phase control system. These measurements would include peak gain, side lobe, depth of first null, side lobe smearing, phase stability and accuracy. Mechanical variations could be introduced into the subarray, and parametric variations of the phase control system could also be made. All measurements would be made with phase control drive signals radiating into the antenna subarray.

Antenna Pointing - Using a 10m x 10m subarray, appropriate phase control system, and antenna pointing system, antenna search, acquisition and tracking performance can be determined. The measurements would be made utilizing the anechoic chamber and antenna range and would include search and acquisition times, tendency for side-lobe acquisition and dynamic tracking capability.

Mechanical Alignment - Tests of the mechanical alignment system (required for initial alignment and subsequent alignment checks of the subarray mounted on the antenna structure) would be made for aligning waveguide elements within the subarray for the above tests. The microwave and laser laboratory would be used for refining alignment techniques and for actual alignment checks on the test subarray elements/waveguides.

Electromagnetic Interference - These tests would be accomplished in the anechoic chamber by testing the radiation characteristics of the microwave generators as integrated into the MW transmitting antenna. Harmonic and spurious noise content of the radiated spectrum would be checked as functions of voltage and current variations from the prime source. Frequency drift, RF amplitude variations and phase stability would also be checked together with isolation characteristics between the MW beam and the pointing and phase control systems.

Thermal-Vacuum Operation - Dissipation efficiency of waste heat from the integrated antenna would be measured in the thermal-vacuum chamber. This would include dissipation capability of the microwave generator passive radiators as well as the subarray waveguides and structure. Simulated GEO/LEO thermal cycling would be introduced onto the 10m x 10m subarray.

In addition to the thermal tests, another important area to be checked is the voltage breakdown characteristics of the microwave generators and subarray waveguides. Multipacting, corona discharge, and possibly plasma interactions would be checked. Environment in the immediate vicinity of the SPS transmitting antenna would be simulated to the maximum extent feasible. Other parametric measurements on the operating subarray would be made where advisable after further study.

In addition to the above tests on the SPS MW System, power distribution tests of some degree may be able to be included. A general requirement, inherent in all the above tests with the microwave generators, is the additional prime power needed at the test facilities. This requirement could be met with either modifications to supplement prime power capability or by means of portable power units. The latter seems to be attractive from the cost and flexibility standpoints.

Early ground tests will be required to aid in development of a data base for the SPS programmatic decision points. The above MW System tests are required to provide a data base in this area. Subsequent study will better define the ground tests as outlined above.

IX. PROGRAM DEVELOPMENT PLAN

B. TECHNOLOGY ADVANCEMENT PLAN 1980-1987

3. Flight Activities

Clarke Covington
Spacecraft Design Division

The Technology Advancement Requirements Study (JSC-12702) identified critical technology areas and categorized the concomitant test requirements into ground tests, flight experiments (components and subsystems), and flight projects (integrated system flight tests requiring the interaction of two or more subsystems). The following sections present descriptions of flight experiments and flight projects necessary in the development program for an SPS, and an analysis of the scale factors involved in deriving meaningful test requirements for testing the SPS structure in low earth orbit.

a. Flight Experiments

Figure IX-B-3 typifies the range of experiments which require going into space for SPS technology advancement. The simpler end of the range involves "suitcase" or package-size experiments which can be flown along with other payloads and accomplished by the crew in the space environment. An example is space welding which is critical to the automated fabrication process. Ultrasonic welding techniques developed on the ground would be applied with development equipment to candidate structural materials in space with the test articles returned to the ground for evaluation. Experiments of this type would begin in 1980 in the early operational period of the shuttle.

The GEO environment/materials experiment would use an Interim Upper Stage (IUS) to put a satellite in GEO to sense the SPS operational environmental parameters and telemeter them to the ground for verifying and improving analytical models. Environmental effects upon materials critical to the achievement of satellite design lifetime would be evaluated.

Subsystem experiments would be beyond the component level and involve significant pieces of or entire subsystems. A pertinent example of a subsystem experiment is a test of an entire scaled antenna subarray where microwave energy transmission could be made to sensors extended out on the shuttle remote manipulator system (RMS). Operating in a space environment allows operational evaluation of power generator and antenna efficiencies, heat rejection, and transmission efficiency. Subsystem experiments would be required in the 1981-1984 period.

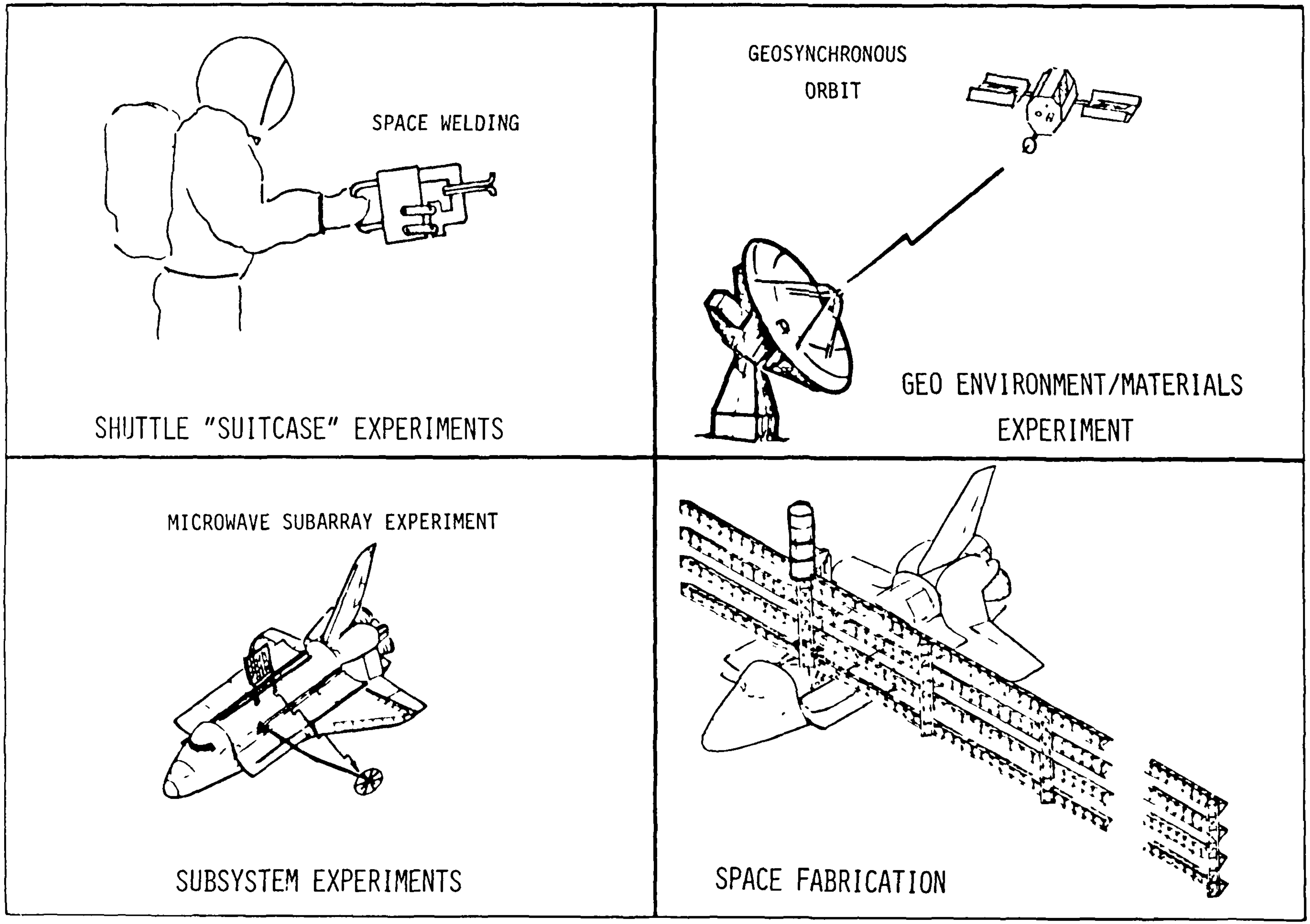


FIGURE IX-B-3 - TYPICAL FLIGHT EXPERIMENTS

The Space Fabrication Experiment is the first flight test in the development of a new discipline--space construction. An automated fabrication module (or "beam builder"), a rudimentary construction facility (or "jig"), and a construction crew (extra-vehicular orbiter crew) would operate together in this experiment. A test structure would be constructed for evaluation of the beam builder, construction processes and techniques, and would stay attached to the orbiter during the load tests. This experiment would be required in about 1982 and represents close to the upper limit in scope of single-shuttle flight experiments. The results of an initial in-house study of an automated space construction experiment are given in the following paragraphs on the next page.

Automated Space Construction Experiment

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Spacecraft Design Division

In-house concept design studies have been made of a beam builder that is compatible with the orbiter, and a construction experiment that could be conducted using the orbiter as a construction base. The results of the study indicate that such an experiment could, in a cost effective manner, explore many of the fundamental issues and technical problems associated with construction in space. The study also indicates that the orbiter, from the configuration standpoint, is a remarkably versatile payload carrier and operational spacecraft.

Beam Builder - The beam builder concept depicted in figure IX-B-4 continuously and automatically fabricates a triangular cross-section truss (dimensions on the order of 1.5 meters on the side) of practically any desired length, from strip material stored on reels. The strip material is processed and wound onto the reels as an earth-based operation, and the beam builder may be "reloaded" with material as often as desired. A likely material is graphite fiber reinforced thermoplastic (such as polysulfone), as is used in this design. The truss consists of three cap members (one at each corner of the triangle) plus side members which interconnect the caps to complete the truss. In operation, a cap is formed as follows. Strip material unwinds from the reel and travels through a heating module where it is heated by radiant electric heaters, for example, to its plastic, or forming, temperature (about 320°C). Then it travels through a series of matched rollers which form it from a flat strip to a flanged, triangular shape. As it leaves the last of the forming rollers, it enters a cooling section where it is cooled to the "rigid" state (about 135°C) by radiation to cold plates, for example. Now it is a finished cap, moving through the beam builder to be joined to the side members. The side members are fabricated as follows. Material is processed at earth-based facilities into a flat, patterned sheet, as indicated on the illustration, and wound onto a reel (three identical reels of material for the three sides). The material is unwound from the reel, heated in the same manner as the caps, and stiffening beads (the "beads" are not shown in the illustration) are formed into the crossmember portions by a press forming mechanism (which momentarily translates the forming dies to match the velocity of the strip material as it moves through the beam builder). The material is then cooled (radiation to cold plates) and is positioned onto the caps where it is joined by ultrasonic spot welders. (Ultrasonic vibration produces melting of the thermoplastic at the faying surface with subsequent fusion of the surfaces.)

Precise coordination of the velocity of all members is required to fabricate a "straight" truss member and to avoid "buckling" of a cap member, for example, in case that cap is being driven through the forming rollers faster than the other caps.

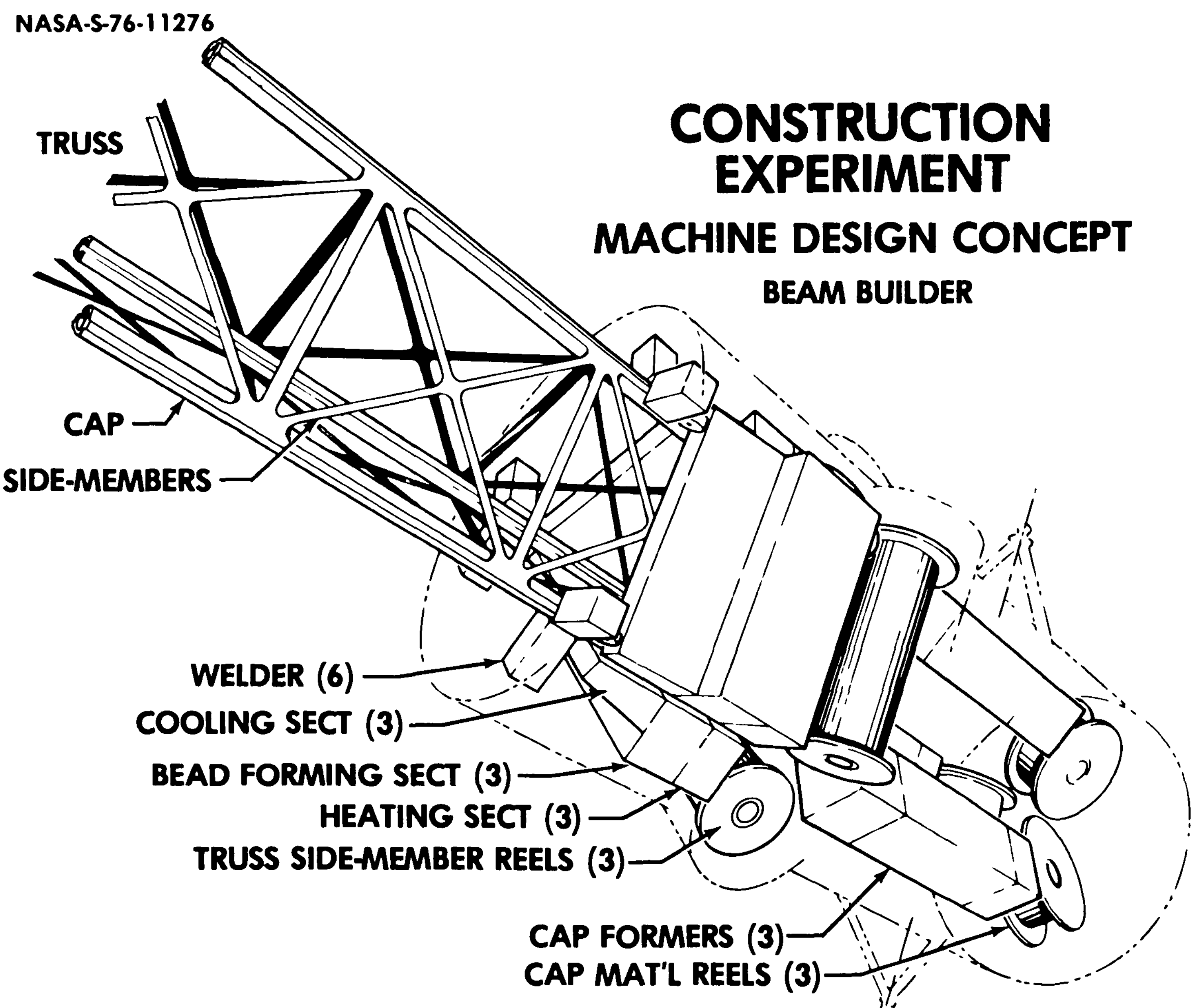

FIGURE IX-B-4 - BEAM BUILDER CONCEPT

A "closed-loop" type control system employing appropriate sensors, electronics and servo-mechanisms will be employed to control and coordinate the machine operations.

The rate of fabrication may be relatively slow, by commercial standards, to reduce power demands and minimize the weight and size of the beam builder. A fabrication rate of about one and one-half meters per minute is considered to be appropriate. However, at this slow rate, the machine could fabricate a one kilometer long truss in less than 12 hours.

The reel sizes indicated on the drawing are sufficient to fabricate a length of truss in excess of one kilometer, without reloading the beam builder.

Figure IX-B-5 depicts, schematically, several process options that are representative of those that may be utilized by the beam builder to fabricate a truss beam. A primary objective of initial design studies of the beam builder will be to select the appropriate processes, considering the beam configuration to be fabricated, the material to be used for the beam, and the relative merits of the various fabrication processes.

As indicated by the illustration, the cap material stock is likely to be strip which is stored on reels, either multiple reels supplying thin strips which are "laminated" or consolidated into a single, thicker, strip by the beam builder, or a single reel of strip material of the desired thickness. The choice will depend on the desired final thickness and material type and characteristics. For graphite fiber reinforced thermoplastic material, for example, a single reel is a likely choice. In this case, multiple strips of "pre-preg" tape - each with appropriate fiber orientation - are consolidated into a single composite strip on earth.

Three possible cap-forming processes, as indicated, are "spiral tubeform", "roll-form", and "pultrusion". These basic processes are in regular commercial use today. The spiral tubeform process can form a tubular cap member of relatively large diameter from narrow strip by spirally winding the strip and continuously joining the overlapping edges. A fundamental problem with this process for use in the beam builder, however, is that the forming mechanism plus the material supply reel must rotate about the longitudinal axis of the tube. The roll-form process uses mating rollers to continuously bend the flat strip into shape as it passes between the rollers. Multiple rollers, arranged in series so as to form progressively in "stages" are used for complex shapes, each stage of rollers forming a portion of the final shape. Almost any shape, including a closed section such as a tube, can be roll formed. The pultrusion process uses dies (similar to extrusion dies) through which the flat strip is "pulled" to form the shape. The pultrusion process is most appropriate for thermosetting plastic where heated forming dies produce the formed shape and supply heat to provide the final thermal "cure" of the material.

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MACHINE DESIGN - PROCESS OPTIONS

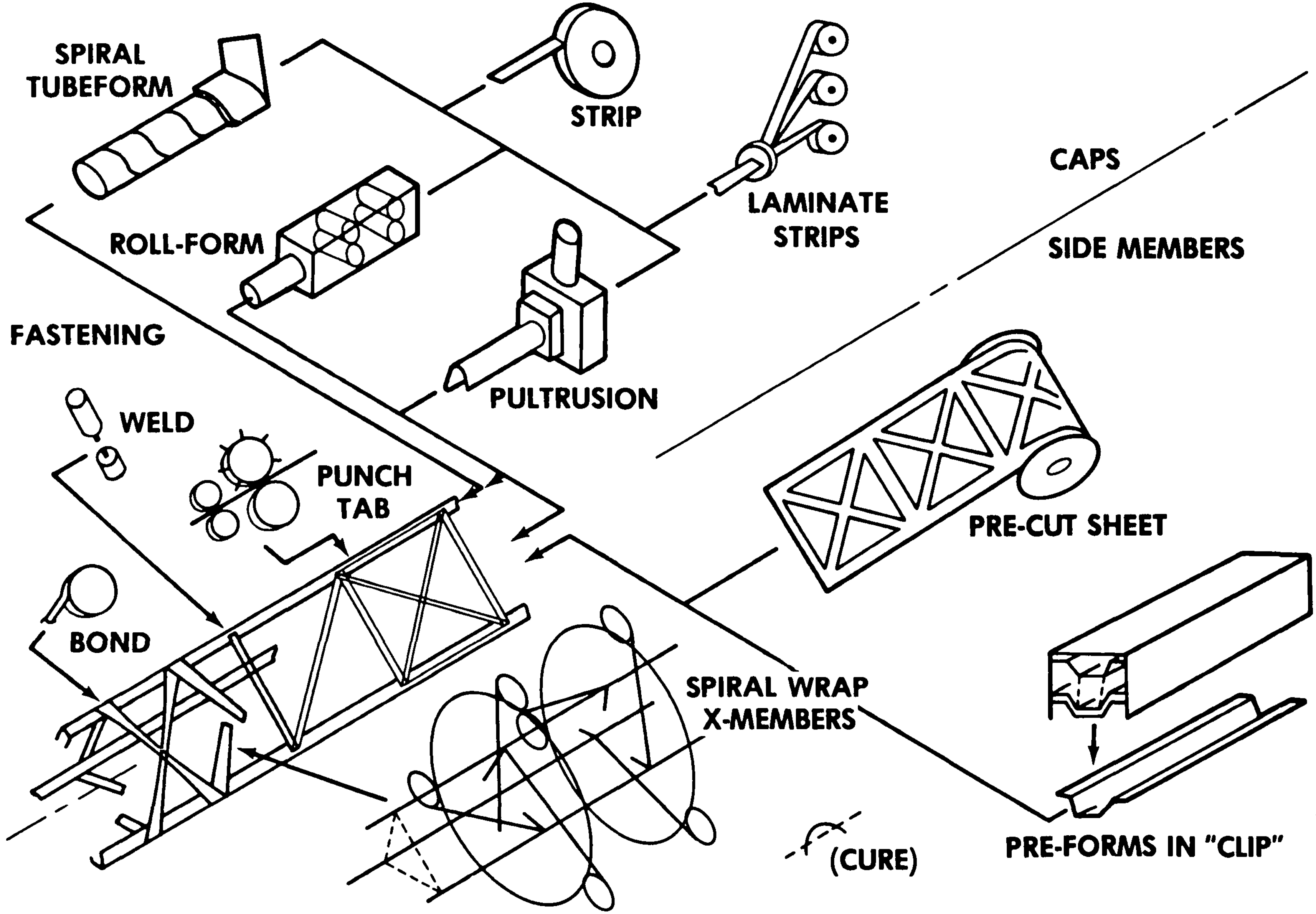

FIGURE IX-B-5 - BEAM BUILDER PROCESS OPTIONS

The side members of the truss beam (cross members and diagonals) may also be formed from strip, using the roll-form or pultrusion process. A continuously formed section would be periodically cut to the appropriate member length to span between the caps, and a mechanism would position each member for fastening to the caps. Side members could also be pre-formed on earth and stored in "clips", from which they would be removed sequentially and assembled into the truss beam by automated mechanisms. The shape of the pre-forms would be selected so that they would stack together, as indicated, in a dense package.

The side members (cross members and diagonals) could be integrated in the form of a pre-cut sheet as shown in the illustration. Instead of cutting from a large sheet, the material could be fabricated in the pattern shown, using automated composite material lay-up machinery similar to that currently used for aircraft structure. Then, during beam builder operation, the sheet is unrolled from its supply reel, stiffening beads or flanges are formed in the appropriate members, and the sheet is joined to the caps.

An entirely different process from those previously described for fabrication of truss side members involves spirally wrapping tape around the caps from six reels, as indicated. The tape would be a thermosetting composite which would be designed to thermally cure to a curved cross section shape as indicated, thus being capable of compression loading. Tension diagonals (X-members) may simply be cables or wires fed from supply reels in the spiral wrap manner, or the reels may be fixed and additional mechanisms employed to install the wires in a "back and forth" action between compression cross members.

For fastening the side members to the caps, three appropriate techniques are bonding, welding, and punch tab. The punch tab technique would only be considered for metals, such as aluminum, and involves shearing a small tab from the pieces to be joined and bending it over to form a joint somewhat like a hollow rivet. Welding would likely be resistance spot welding for metals and ultrasonic spot welding for thermoplastics. Bonding would involve the application of a tape, activated by heat, between the faying surfaces to be joined. The use of rivets or bolts is not contemplated because of the problem of debris from punched or drilled holes.

Construction Experiment - The construction experiment, utilizing the shuttle as the launch vehicle and the construction base, has the basic objective of initiating development of the technology of construction in space of large, low density structural systems. The basic approach is to construct a large structural assembly, or platform, in orbit, from strip stock material. A single shuttle mission is adequate, requiring a four-man crew and about seven days mission duration. Certain basic engineering tests would be performed on the structure, and appropriate scientific experiment equipment could be added as a secondary mission benefit. A second shuttle mission could revisit the platform and perform installation of additional equipment.

Figure IX-B-6 indicates a possible structural platform configuration, and figure IX-B-7 indicates the basic beam configuration that would be fabricated by the beam builder. The launch configuration with the structure fabrication system installed in the orbiter is shown in figure IX-B-8. This figure shows that the fabrication system is deployed 90° for operation in orbit. The structure fabrication system consists primarily of an assembly jig, a beam builder (previously described), and a beam builder positioning mechanism. Figure IX-B-9 illustrates the system in operation. The beam builder is positioned to fabricate, in sequence, four longitudinal truss members, each 1.5 meters wide and about 200 meters long, and each being fabricated "in situ", such that when completed and cut off from the beam builder, the assembly jig will grip the beams through a system of rollers, maintaining their relative positions. In the illustration of figure IX-B-9, the beam builder has just commenced fabrication of the fourth longitudinal. By repositioning the beam builder to fabricate the longitudinals in their proper relative positions, the problem of repositioning the long members, with their very high mass moments of inertia about a transverse axis plus their flexibility, is avoided.

In the illustration of figure IX-B-10, the beam builder is in position to fabricate the 10.5 meter long cross members, in situ, with the first cross member nearing completion. When the first cross member is completed, it will be cut off from the beam builder and gripped by the assembly jig rollers. Crewmen will then exit from the orbiter through its airlock and attach the cross member to the longitudinals by using handheld ultrasonic welders to join two caps of the triangular cross member truss to the caps of each longitudinal where they cross (four places at each longitudinal). After the first cross member is attached, the structural assembly will be moved through the jig by driving appropriate rollers to a position for installation of another cross member about 20 meters from the first. This operation is repeated until nine cross members are installed, to complete the structural platform (about 10.5 meters wide by 200 meters long).

The crew would be utilized (in extravehicular activities) to attach the cross members, inspect the fabrication process close-up, and aid in assembly jig set-up. Complete automation could be achieved. However, the value of using the crew in the fabrication operations for maximum cost effectiveness is an important part of the experiment.

A summary of the sequence of fabrication of the structural platform, shown schematically in figure IX-B-11, is as follows. The beam builder is first positioned relative to the assembly jig as shown in the left hand view by a positioning mechanism on the jig. It fabricates the first longitudinal beam, to the proper length, and stops operation. The beam is "gripped" by rollers on the assembly jig and the beam builder cuts off the longitudinal beam. Then the beam builder is moved along a track on the side of the assembly jig until it is in position to fabricate the second longitudinal, adjacent and parallel to the first longitudinal, in the same operational manner. This sequence is repeated until the fourth longitudinal is completed.

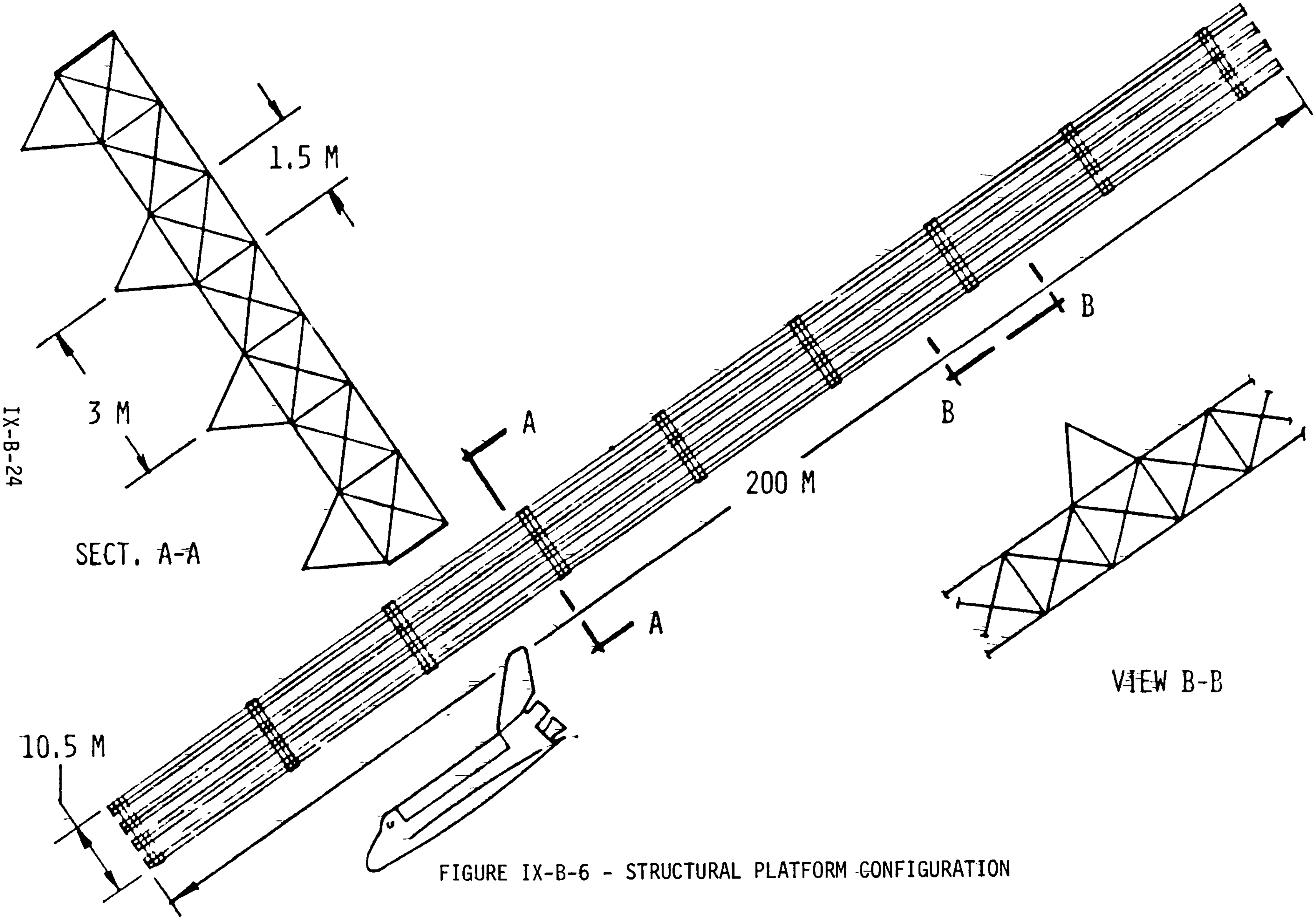

FIGURE IX-B-6 - STRUCTURAL PLATFORM CONFIGURATION

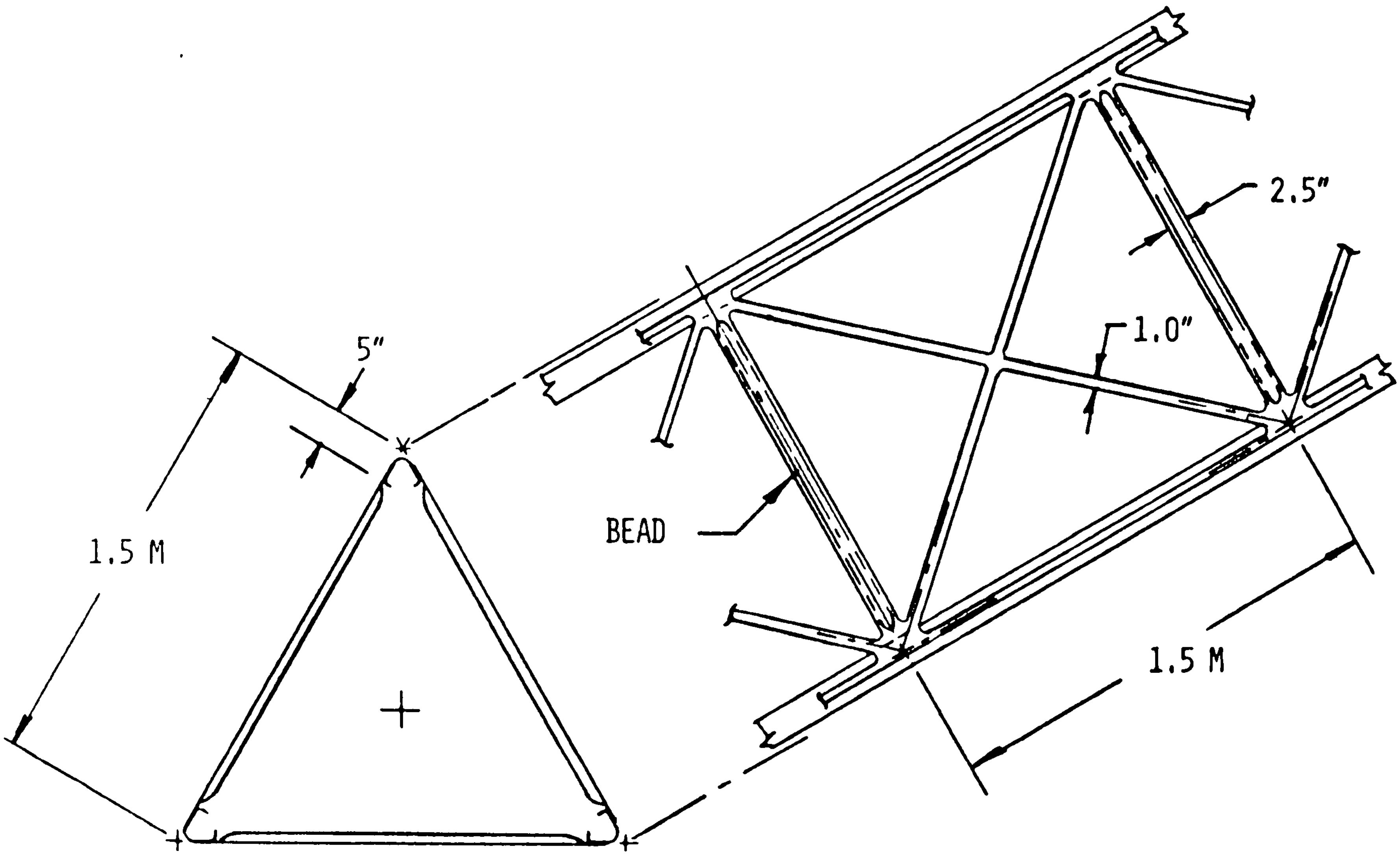

FIGURE IX-B-7 - BEAM CONFIGURATION

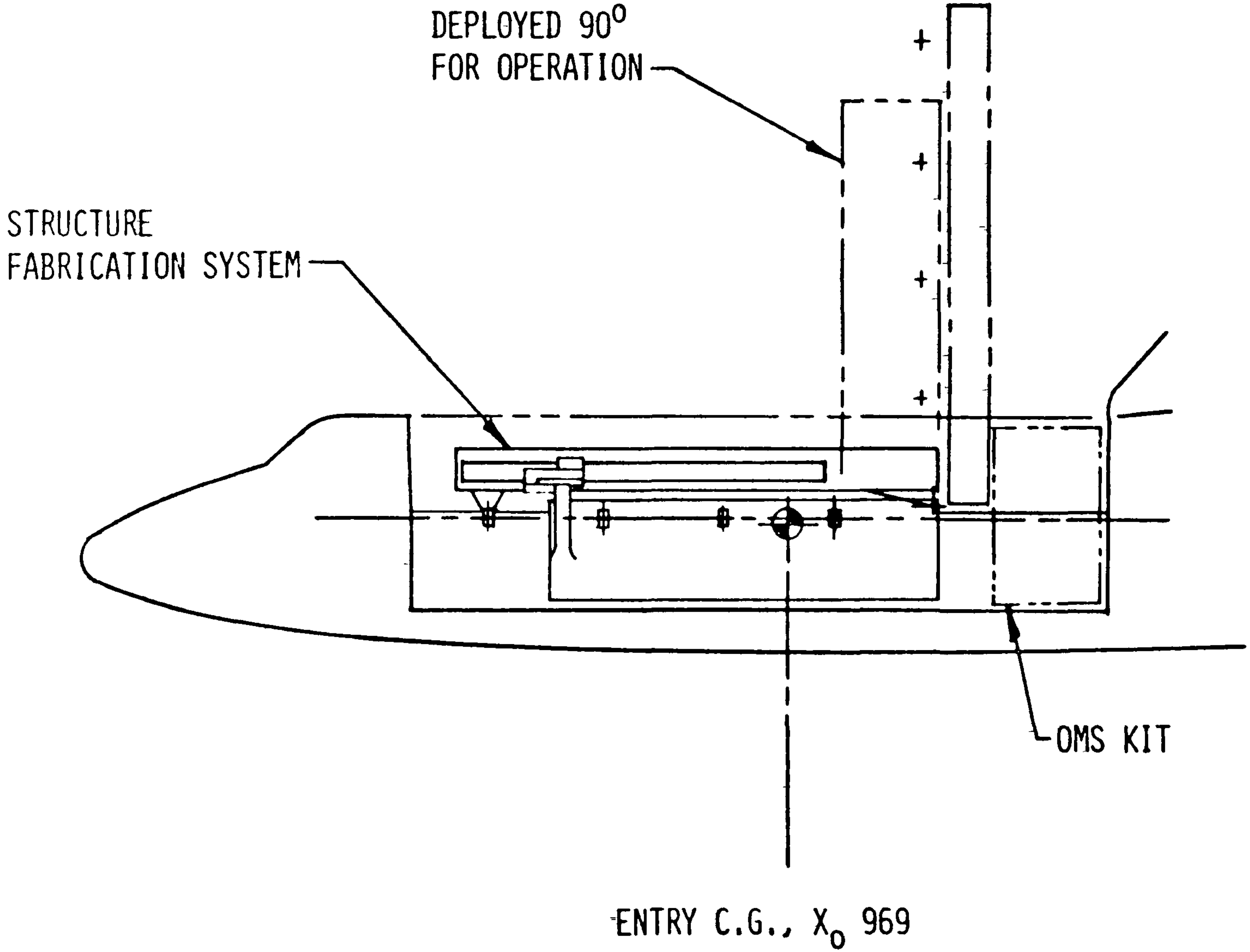

FIGURE IX-B-8 - LAUNCH CONFIGURATION

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STRUCTURE FABRICATION SYSTEM CONCEPT FOR LADDER CONFIGURATION

LONGITUDINALS

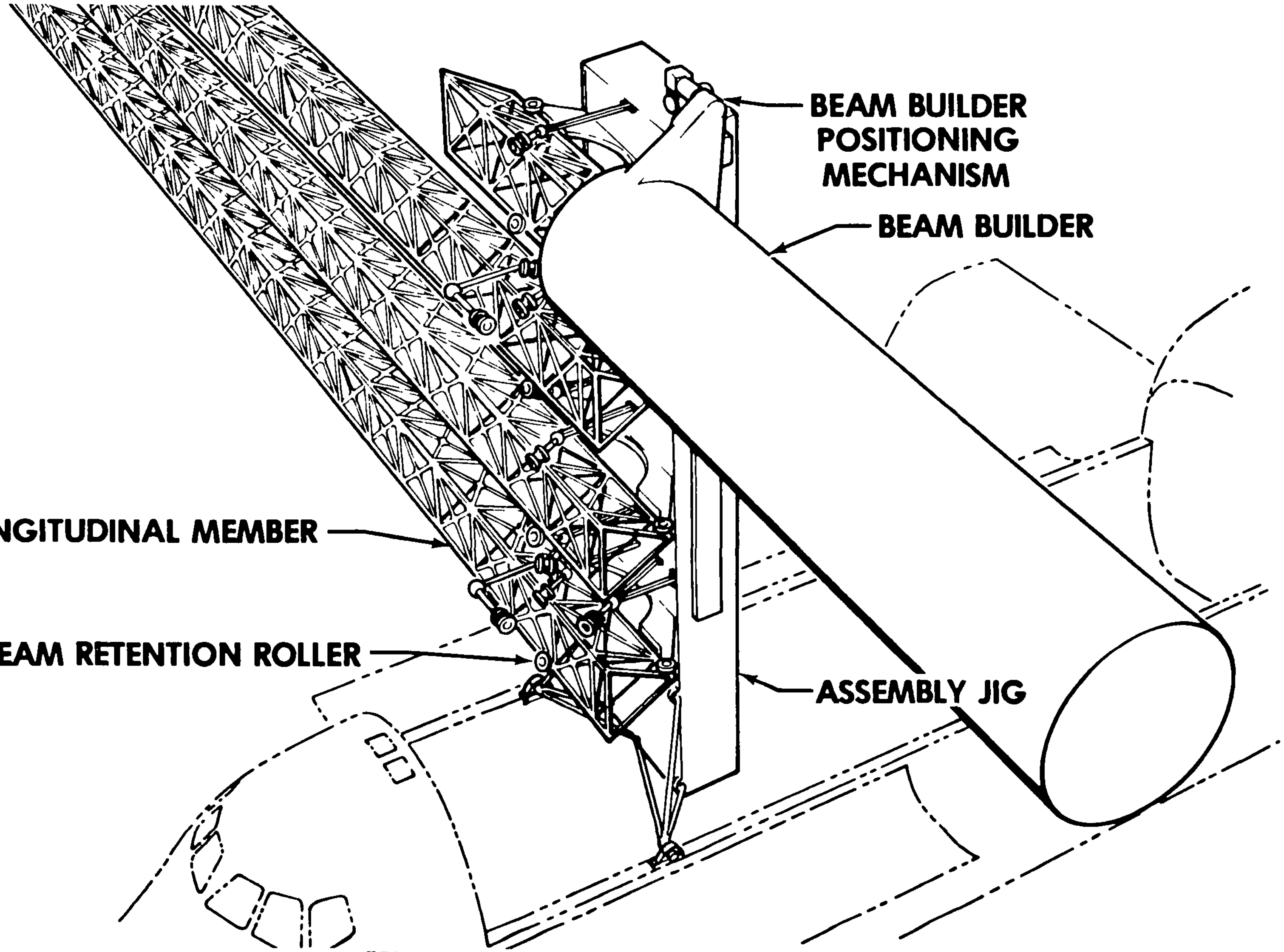

FIGURE IX-B-9 - FABRICATION OF LONGITUDINAL MEMBERS

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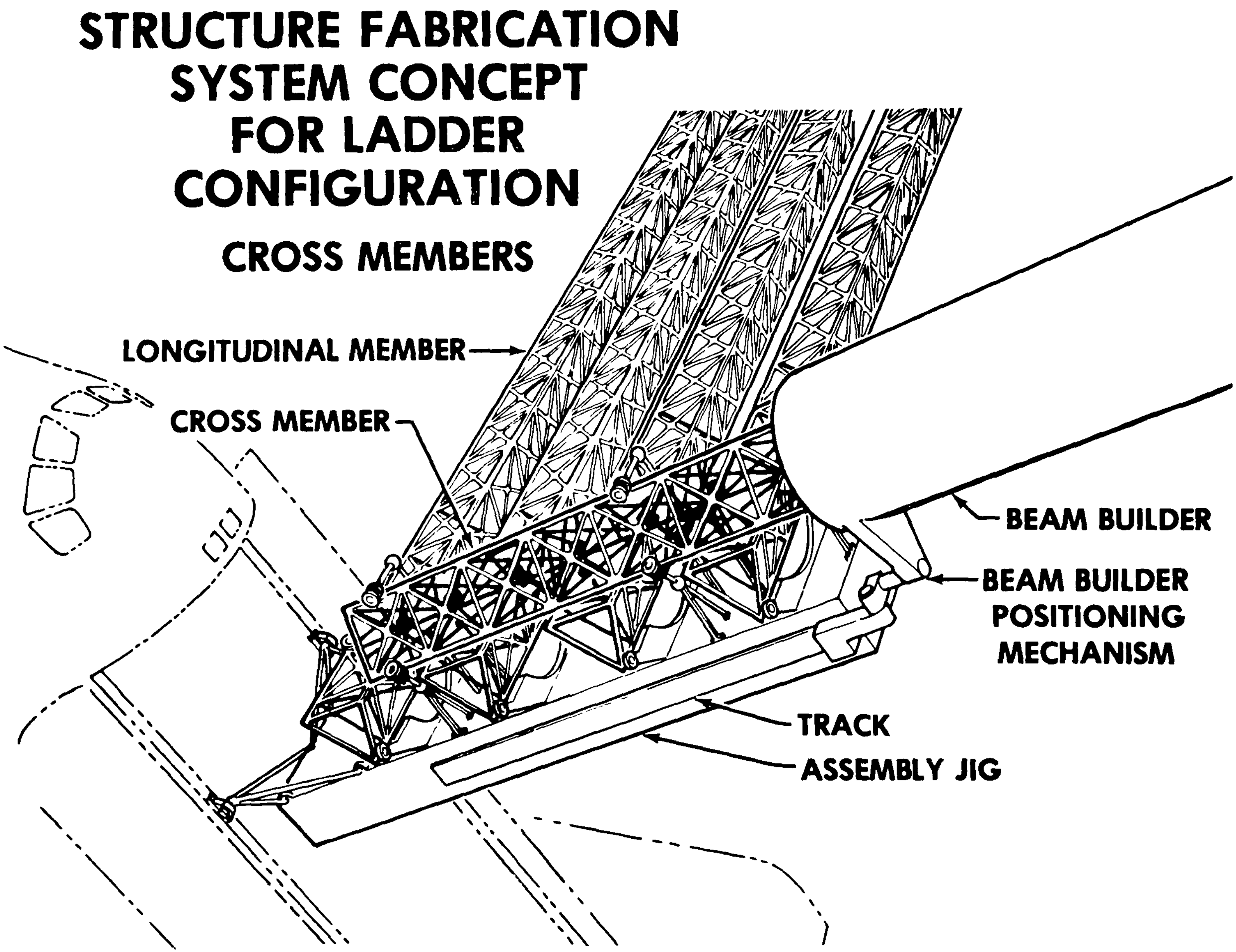

FIGURE IX-B-10 - FABRICATION OF CROSS MEMBERS

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FABRICATION SEQUENCE LADDER CONFIGURATION

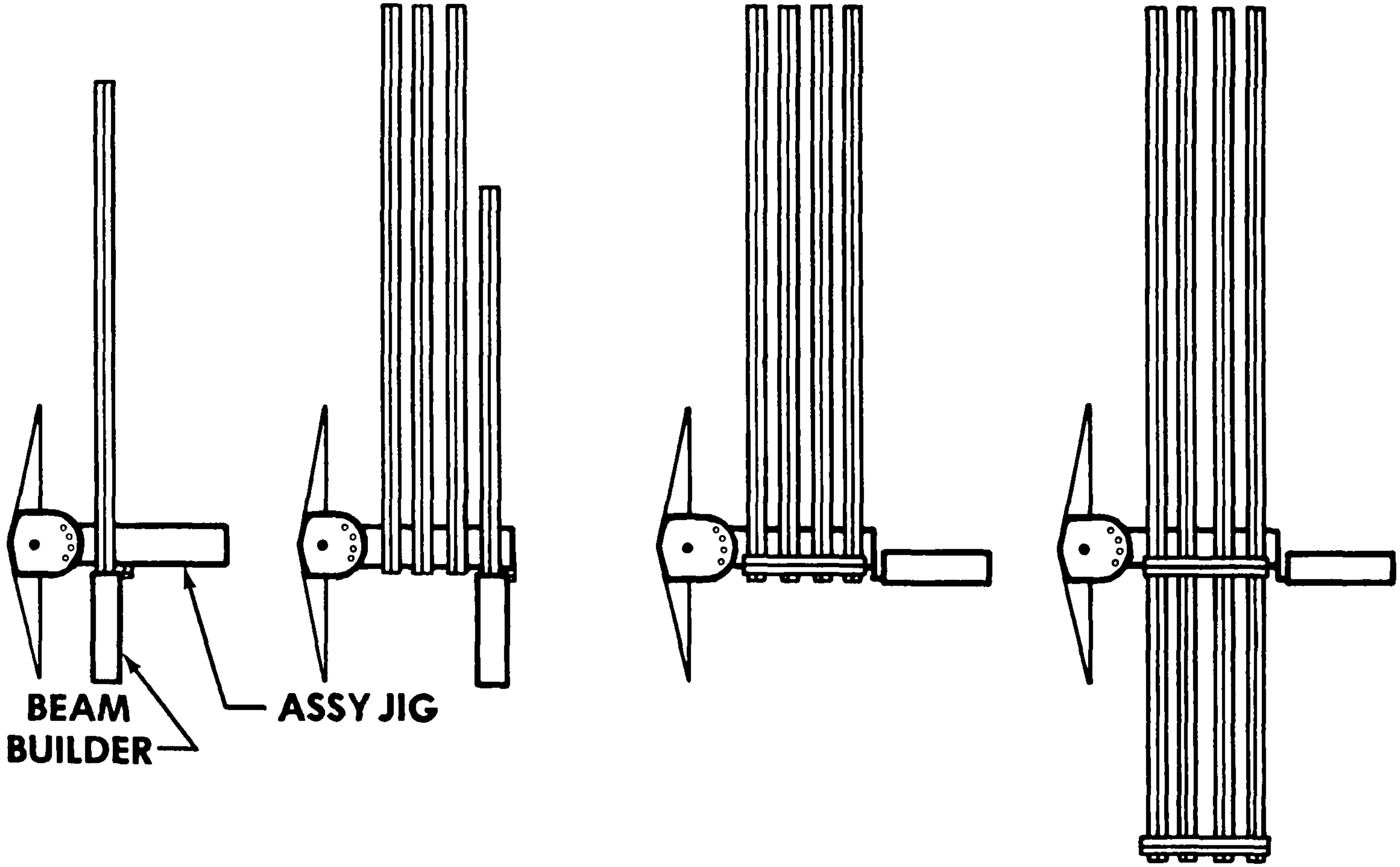

FIGURE IX-B-11 - STRUCTURAL PLATFORM FABRICATION SEQUENCE

The beam builder is then rotated into the position to fabricate the first cross member. After it is completed, the cross member is joined to the longitudinals by an orbiter crewman using a portable ultrasonic spotwelder (16 places - where the cross member and longitudinal beam cap members cross each other).

The partially constructed platform is then driven "across" the assembly jig by the retaining rollers until the longitudinals are in position relative to the beam builder for fabrication and attachment of the second cross member in the same manner as the first. These events are repeated until installation of the last cross member, which completes the construction of the platform.

After completion of the platform, various engineering tests and experiments would be performed while it is attached to the orbiter, and a myriad of subsequent mission options are possible. The platform would, finally, be released from the jig and the jig and beam builder returned to earth in the orbiter.

Figure IX-B-12 shows a concept for fittings to join the longitudinals and cross members of the structural platform. An identical fitting is attached to the cross member and the longitudinal where the caps of each cross at 90°. These fittings might be installed by ultrasonic welding during fabrication of the beams, either automatically by the beam builder or manually by EVA crewmen. Then crewmen would join the fittings using handheld ultrasonic welders. The fittings provide appropriate load introduction and distribution. Instead of fittings, it may be adequate to simply weld the caps together where they cross.

Figure IX-B-13 illustrates the installation of subsystems to the structural platform. Modularized equipment assemblies would be carried in the orbiter payload bay and installed onto the platform, using the orbiter's remote manipulator system (RMS) to move the equipment assemblies into position, and an orbiter crewman to make the structural and electrical connections.

Representative subsystems include reaction control (RCS), solar cells and batteries, communications equipment, experiment equipment and data recorders.

Development of the techniques and design features necessary for equipment installation in space is an important objective of the construction experiment.

Figure IX-B-14 indicates possible significant mission events superimposed on a plot of platform altitude versus time resulting from normal orbital decay (without application of orbit-keeping propulsion). Because of its high drag area relative to its mass, the platform should be constructed at an orbital altitude of approximately 550 kilometers (300 nm) to insure that it has adequate orbital lifetime for reasonable utilization of its experiment potentialities.

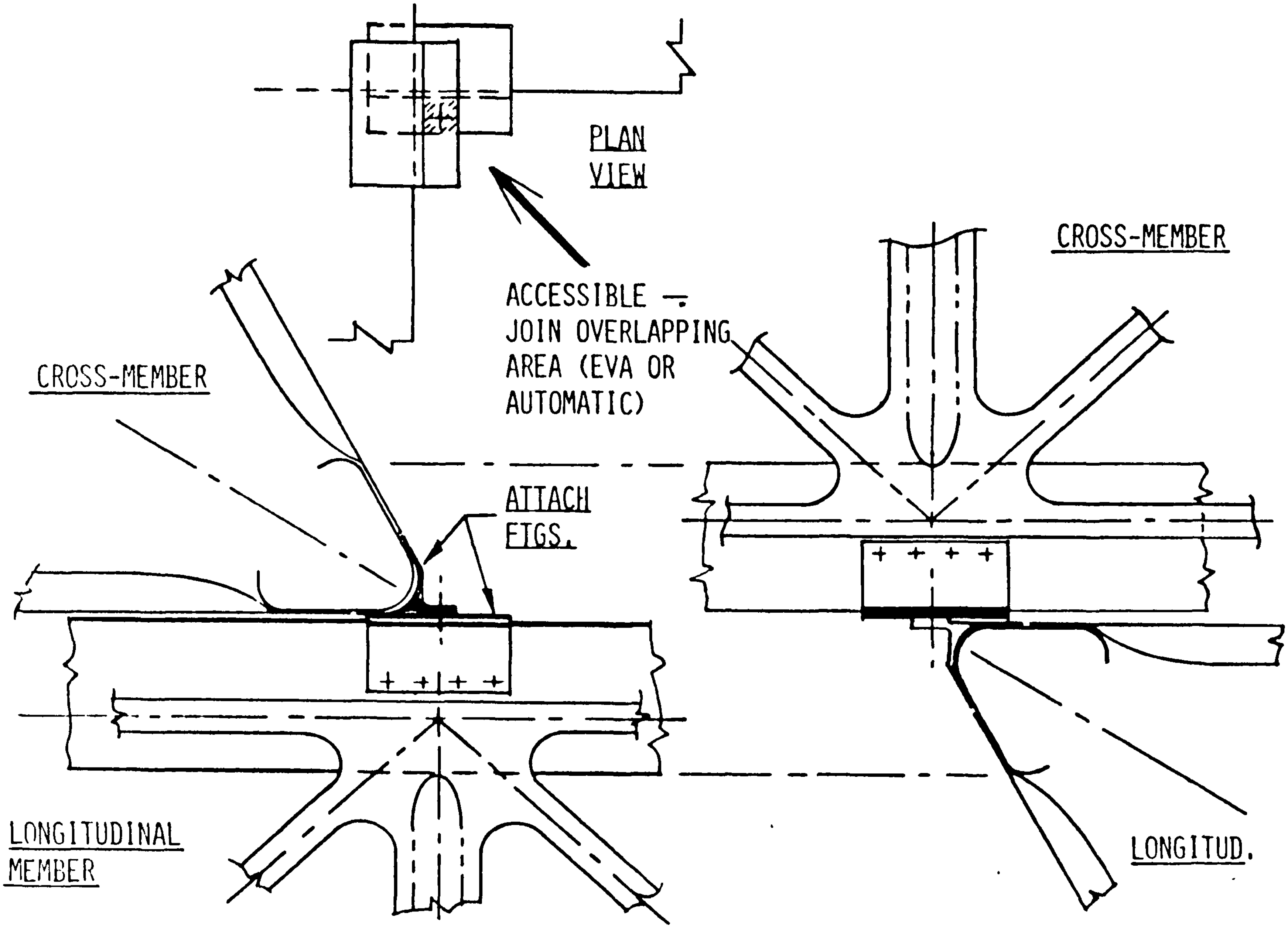

FIGURE IX-B-12 - CONCEPT FOR JOINING BEAMS

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SUBSYSTEM INSTALLATION

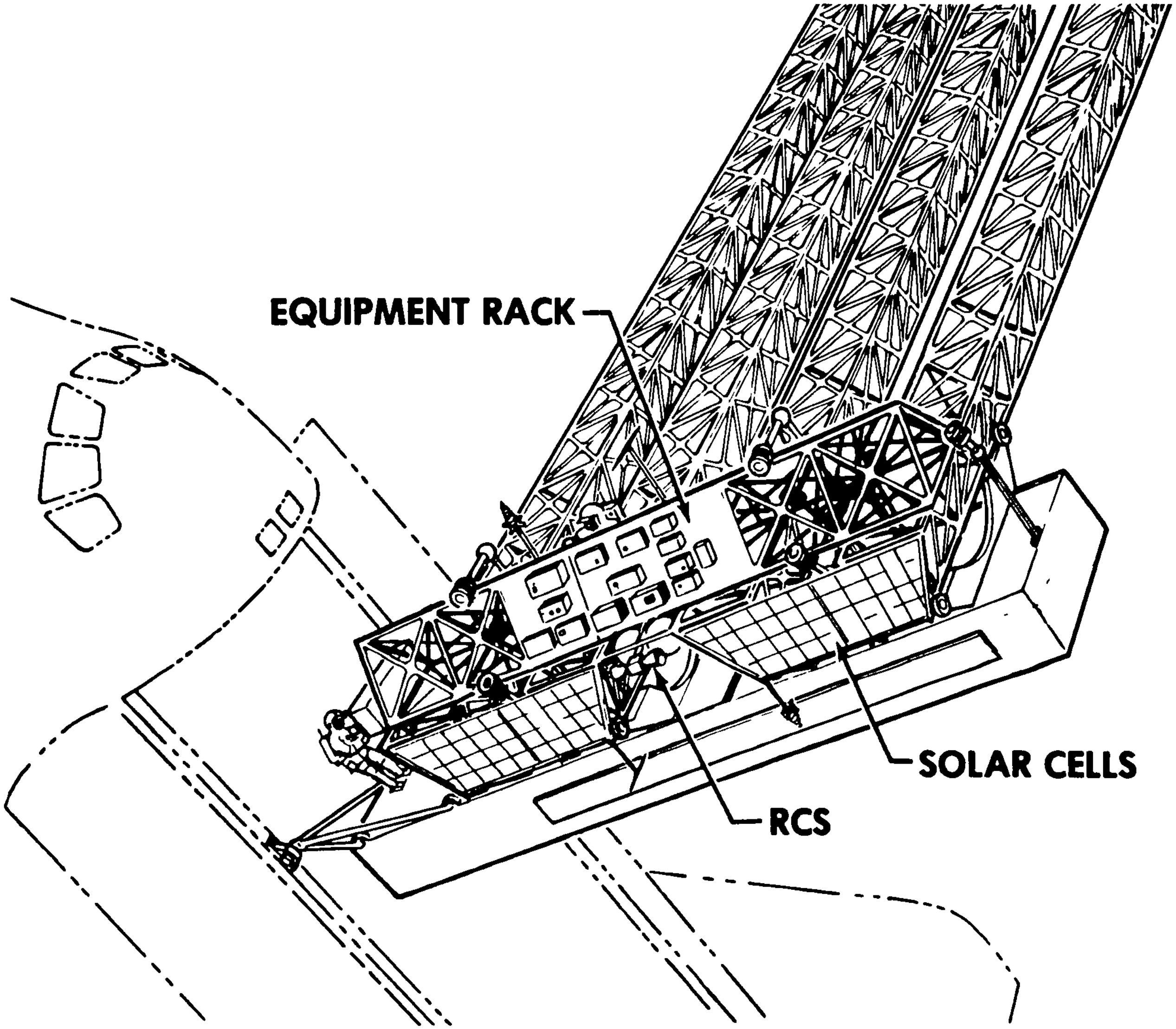

FIGURE IX-B-13 - SUBSYSTEM INSTALLATION

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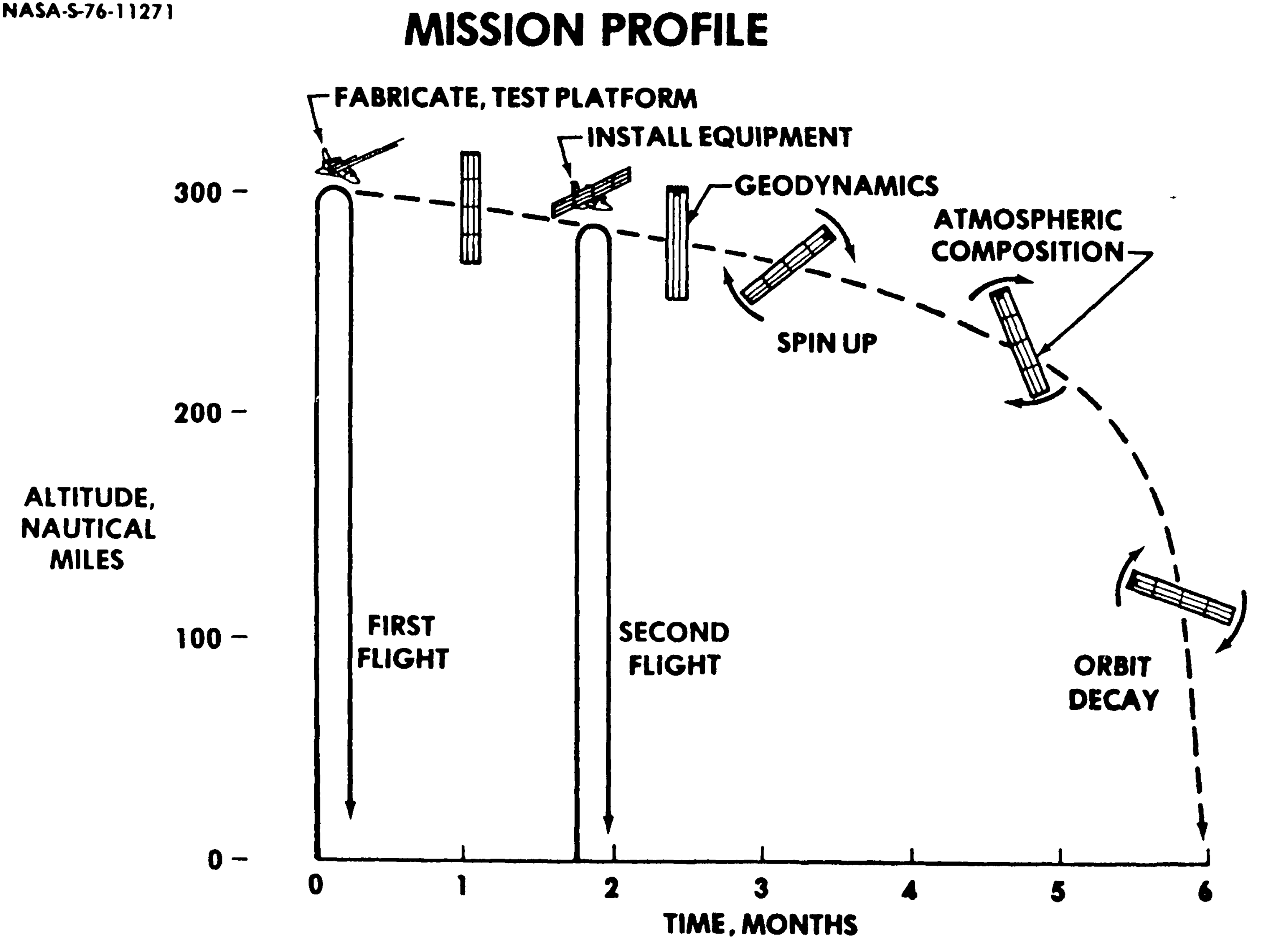

FIGURE IX-B-14 - MISSION PROFILE

The platform can be constructed, and important structural engineering tests can be performed, utilizing a single shuttle flight of seven days duration. The platform would be separated from the orbiter at the end of the seven days and the orbiter returned to earth. Subsequently, the platform would be tracked by radar from earth to determine its actual orbital decay rate. The platform would be in a free-drift attitude mode after separation from the orbiter, but would tend to align itself along a radius toward the earth's center due to gravity gradient forces.

A second shuttle flight is contemplated about six weeks later, wherein the platform is reattached to the assembly jig that was used to construct it on the first flight. The development of the technique and equipment to "dock" the orbiter to the large, lightweight structural platform is an important mission objective of the second flight - being a requirement for full utilization of space construction. A wide range of subsequent accomplishments are possible on the second flight. For example, solar cell "blankets" could be installed on the platform to create a space solar power test bed capable of producing on the order of 300 kilowatts of electrical power from the sun. Reaction control systems could be added, to investigate the technology of attitude control and propulsion of large, relatively flexible structural assemblies. Special equipment could be installed to perform experiments utilizing the unique, large size of the platform, and its rapid orbital decay rate. The mission profile indicates two such experimental possibilities, the geodynamics and atmospheric composition experiments. For the geodynamics experiment, the platform's orbital parameters are very accurately tracked from the ground and a satellite in synchronous orbit, resulting in more accurate knowledge of the earth's mass distribution. For the atmospheric composition experiment, a laser emitter and reflector are installed at opposite ends of the platform and the platform is set into rotation by the reaction control system. During the subsequent orbital decay period, the laser device obtains data that allows determination of the atmospheric composition from that initial altitude until entry into the lower atmosphere.

During atmospheric entry, the platform will be entirely "burned", constituting no hazard to the earth's surface.

IX. PROGRAM DEVELOPMENT PLAN

B. TECHNOLOGY ADVANCEMENT PLAN 1980-1987

3. Flight Activities

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b. Flight Projects - In the SPS technology advancement program, each of the development objectives would be met with the simplest test format which could satisfy that test objective. As much testing as possible would be done on the ground, with only those experiments requiring the unique environment of space being forced to orbit for accomplishment. Some of the requirements for space experiments need the operation of two or more subsystem elements, and initial evaluation indicates that all of these experiment requirements can be satisfied by grouping them conceptually into three flight projects which would use the shuttle in the 1984-1987 time frame. Figure IX-B-15 shows these three flight project concepts which have been identified to satisfy the system development requirements of a reference 1995 operational SPS system.

The first is a Microwave Energy Transmission Test Project which can satisfy experiment and development objectives in the following four primary areas:

1) Microwave Power Transmission System
   - Investigation of thermal effects on the transmitting antenna
   - Test and evaluation of phase control system
   - Power transmission efficiency

2) Photovoltaic Power Generation
   - High voltage DC utilization and switching
   - Investigation of high-voltage power loss to surrounding plasma

3) System Construction Test and Evaluation
   - Automated fabrication process
   - Large element assembly
   - Large structures deployment

4) Space Structures
   - Investigate ultra-lightweight large structures
   - Investigate structure-control system interaction

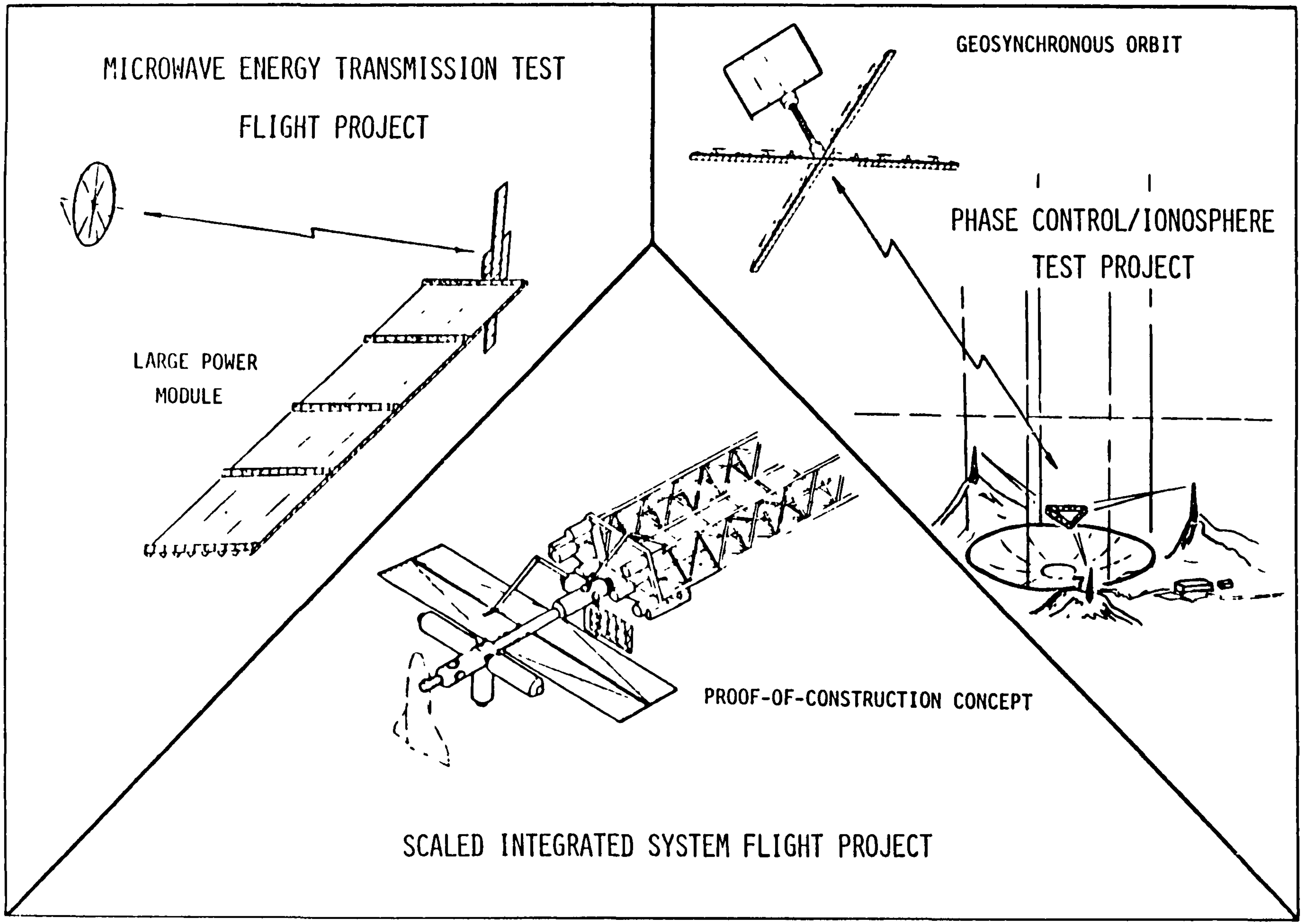

FIGURE IX-B-15 - TYPICAL FLIGHT PROJECTS

In this flight project concept, a large power module capable of generating D.C. power in the 200-500 range supplies electrical power across a rotating interface joint to a test transmitting antenna made up of several 3m x 3m subarrays. The antenna could be operated in two separate test configurations for thermal and phase control tests. The center subarray would contain four Klystron microwave power generators, and the other surrounding subarrays would each have one. Operating the four center Klystrons at full power and the others near half-power would approximate the thermal conditions on an operational 1-Km diameter antenna. Power would be transmitted to a space test rectenna which could be a structural frame with rectenna element sensors mounted at strategic points and a phase control transmitter in the center. Transmission would be made at a range of about 500m for near-field tests and 16.5-Km for far-field tests, as shown in figure IX-B-16. The objective of the microwave transmission tests are oriented toward a total microwave system performance evaluation using suitable test instrumentation, not the collection of a large amount of the transmitted power. The system operation could be modified slightly to provide intermittent power to the ground for a few minutes each orbit where a 300m-diameter rectenna could collect about 500 W peak from 300 nautical miles.

As shown in figure IX-B-17, the large power module could be constructed in space using the beam builder and techniques developed in the space fabrication experiment utilizing the shuttle as a construction base. Antenna subarrays would be assembled on-orbit into the test antenna configuration using the shuttle RMS. The assembly jig is left attached to the power module during construction, and it contains all the necessary subsystems for orbital operations of the power generating system, and a docking or berthing system to allow subsequent shuttle return flights. The space rectenna can be deployed from the orbiter in orbit using a structure specially designed for folding into the payload bay in high-density form.

Construction of the microwave test project could be accomplished within four shuttle flights and would begin about 1984 with tests occuring in 1985. After completion of the project objectives, the large power module would be placed into service as a space utility power system for other objectives and applications.

The second flight project is a Phase Control/Ionosphere Test which is needed to evaluate the MPTS phase control system from GEO and involves the placement of a deployable crossed-array transmitting antenna and a power supply in GEO using the shuttle and the IUS orbital transfer vehicle. Phase control evaluation tests would be performed at low power levels using high-gain receiving antennas on the ground. The tests would also be run in conjunction with ionosphere heating tests using the Arecibo (or Platville) facility in order to investigate phase control signal/ionosphere interaction. The Arecibo ionosphere test is described in detail in Section VII-A-2. These tests would be scheduled in the 1986-87 time period and would probably be preceded by LEO-to-LEO transmission tests using the same crossed-array configuration.

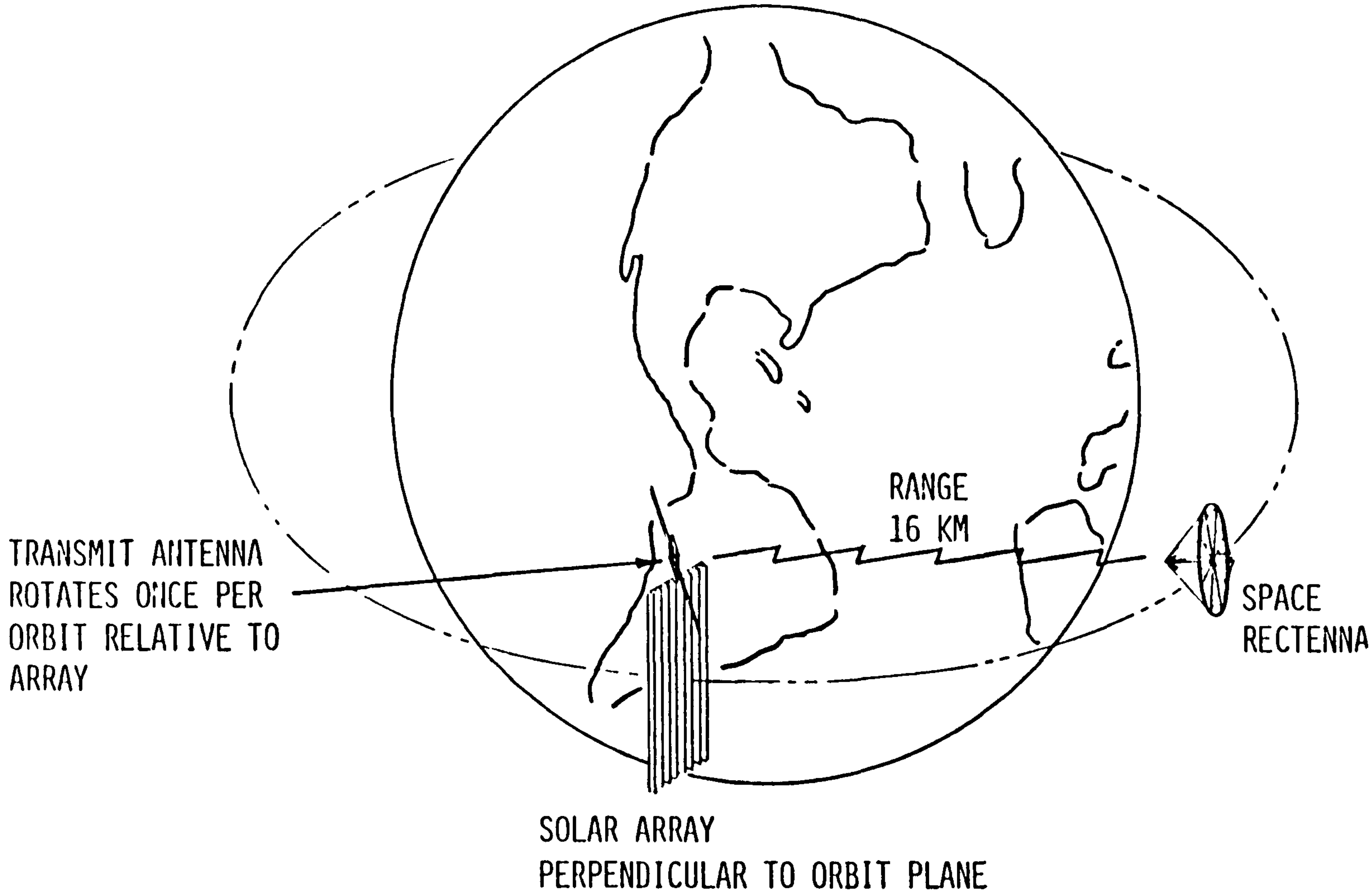

FIGURE IX-B-16 - MICROWAVE ENERGY TRANSMISSION FLIGHT PROJECT

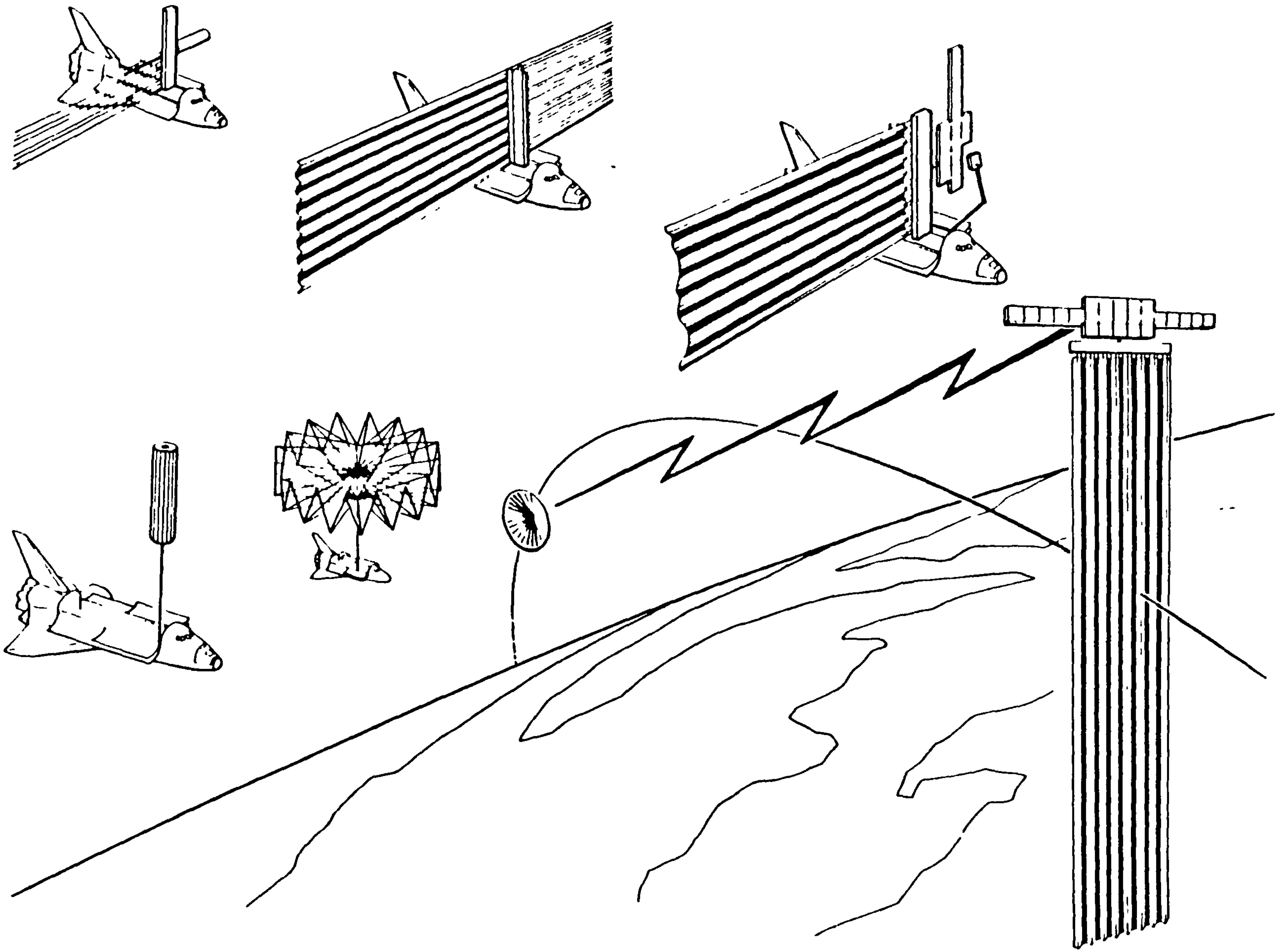

FIGURE IX-B-17 - MICROWAVE ENERGY TRANSMISSION FLIGHT PROJECT

The third project, the Scaled Integrated System Flight Project, accomplishes the final proof-of-construction concept test using the same construction facility concepts and construction processes and techniques planned for a full-scale operational SPS. Whereas previous construction experiments and projects utilized the orbiter as a construction base and extra-vehicular crewmen in the fabrication process, this flight project uses the shuttle as a logistics vehicle only and requires a construction facility and automated fabrication equipment. The resulting scaled-SPS test article provides an end-to-end operational test of the construction and operation of a space power system and provides the design verification and confidence to proceed to a GEO commercial demonstrator or operational SPS. The scope of this flight project is dependent largely on subsequent development planning, but would likely provide peak intermittent power in the 2 to 10 megawatt range to a ground rectenna from low earth orbit.

Sections IX-B-3-b-(1) and (2) detail some of the alternative approaches to the microwave testing currently under study.

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b. Flight Projects

(1) Concept for LEO-to-LEO Microwave System Tests

A low-earth orbit (LEO) to LEO test program for the 1983-1985 time period could provide end-to-end testing of the microwave hardware subsystems-from a pilot beam transmitter to the phased array antenna with the resulting power beam focused upon a beam mapping rectenna. These tests could verify the retrodirective phased array concept and investigate thermal effects within the transmit array.

After the microwave subsystems have been developed and tested on the ground, end-to-end system tests are needed. The performance of the power tubes in a space environment at temperatures up to 485°K need to be measured. The tubes operating in the basic subarray geometry, with the resulting microwave beam measured in the far-field can determine the phase stability of the total array configuration. Losses and the resulting efficiencies of the subsystems can be monitored. The transmission path from LEO-to-LEO, rather than LEO-to-ground, provides a better representation of the dynamics of a full SPS system operating from GEO-to-ground. The intent of the LEO-LEO test program is not to demonstrate a large transfer of microwave power, but rather to test and evaluate the overall system performance.

Objectives:

The objectives of the LEO-LEO microwave tests are:

(1) Thermal Effects Within Antenna

- Phase control degradations due to thermal distortion of waveguides and subarray structure.

  (a) thermal bowing of unsupported waveguides
  (b) expansions within the reference phase distribution system from the center subarray element

- Power tube operation and cooling

(2) Phase Control

- End-to-end verification tests for a retrodirective phased array
- Verify achievable beam transfer efficiency by beam mapping in near field (300 meters)
- Antenna performance versus phase errors and noise correlation regions by beam mapping in far-fields (16 - 32 Km)
- Evaluate RFI Effects

Approach Summary:

This test program involves the construction of a large solar array, transmit array, and beam mapping satellite in low-earth orbit using the shuttle for transportation. One possible configuration has a 4,000m^2 solar array, a transmit array of 189m^2 consisting of 21 - 3m X 3m subarrays fed by klystrons or 128m^2 (64-1m X 2m) of subarrays fed by amplitrons, and a large open-face-satellite with a 360 meter diameter. This satellite has the pilot-beam transmitter and power sensors to measure the microwave beam pattern. It is co-planar with the solar array/transmit array system and separated by 16,500 meters to be in the far-field. The total RF power radiated from this particular configuration is about 370 Kw. It is anticipated that 4-5 shuttle flights would be needed to construct the entire system, with a time schedule of 1983-1985. The data from this program would be used in defining the configurations for later testing in geosynchronous orbit.

A diagram of a possible configuration for the LEO-LEO test is shown in figure IX-B-18 . The microwave antenna as shown in figure IX-B-19 has two operational configurations: one for thermal tests and the other for phase control tests. This particular antenna has klystrons for the power tubes; a similar antenna implemented with amplitrons is shown in figure IX-B-20.

The operational sequence for microwave testing with the klystron tubes is as follows:

- Thermal Tests
  - 9m X 9m antenna (9 subarrays)
  - One klystron for each outer subarray: four klystrons in center subarray for maximum heating
  - Radiated RF power - 368 KW
- Phase Control/Beam Mapping Tests
  - 3m X 45m antenna (15 subarrays)
  - Each subarray has individual phase control system
  - One klystron per subarray - 23 KW output each
  - Radiated RF power - 345 KW
- Range - Antenna to Rectenna
  - Co-planar orbits
  - 16 - 32 KM separation
  - Measurements of 4 - 7 beam sidelobes

A similar test plan could be used with the amplitron tubes.

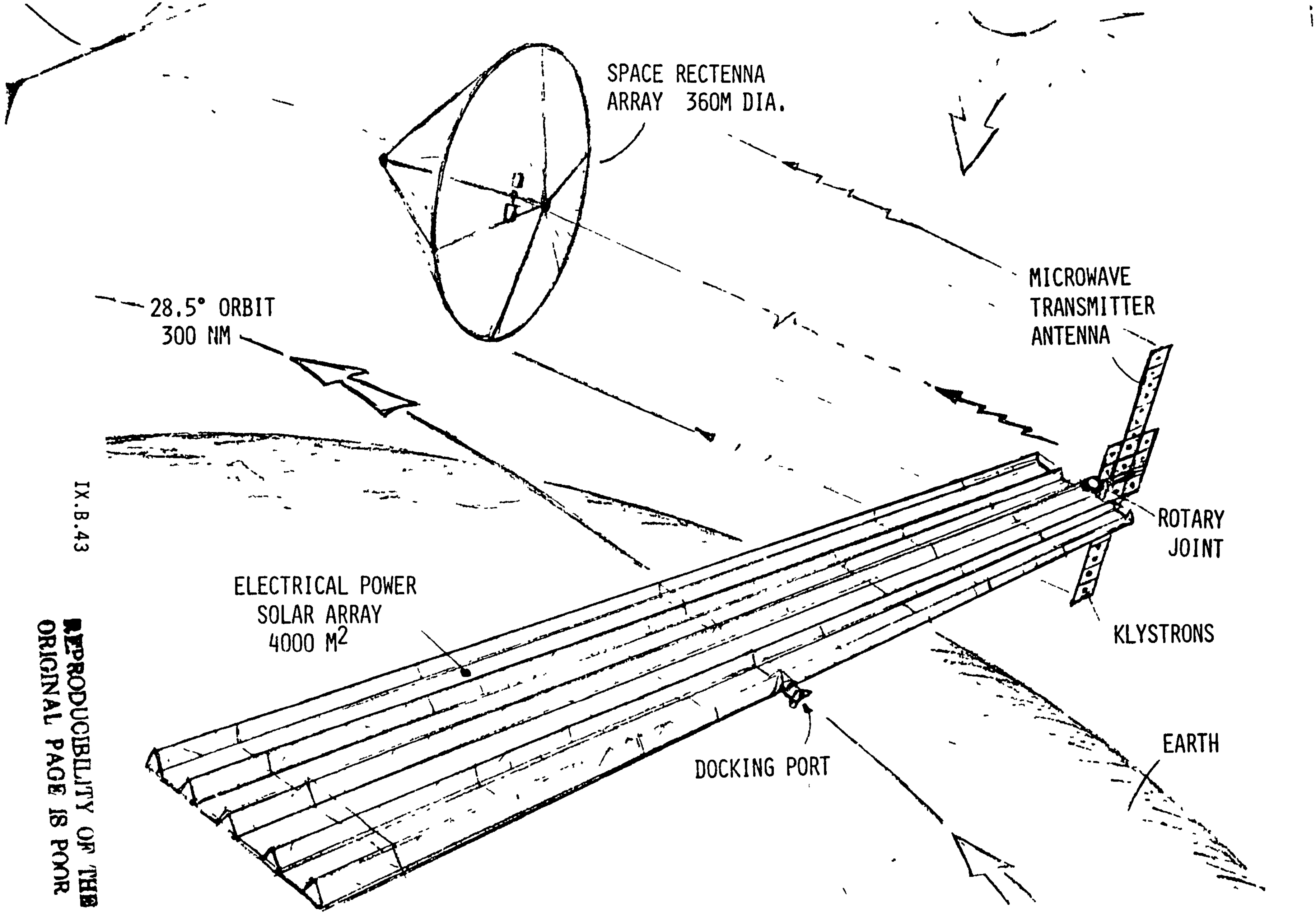


Figure IX-B-18 LEO-LEO Microwave System Test

Figure IX.B-19 -Microwave Power Transmitting Antenna Using Klystrons

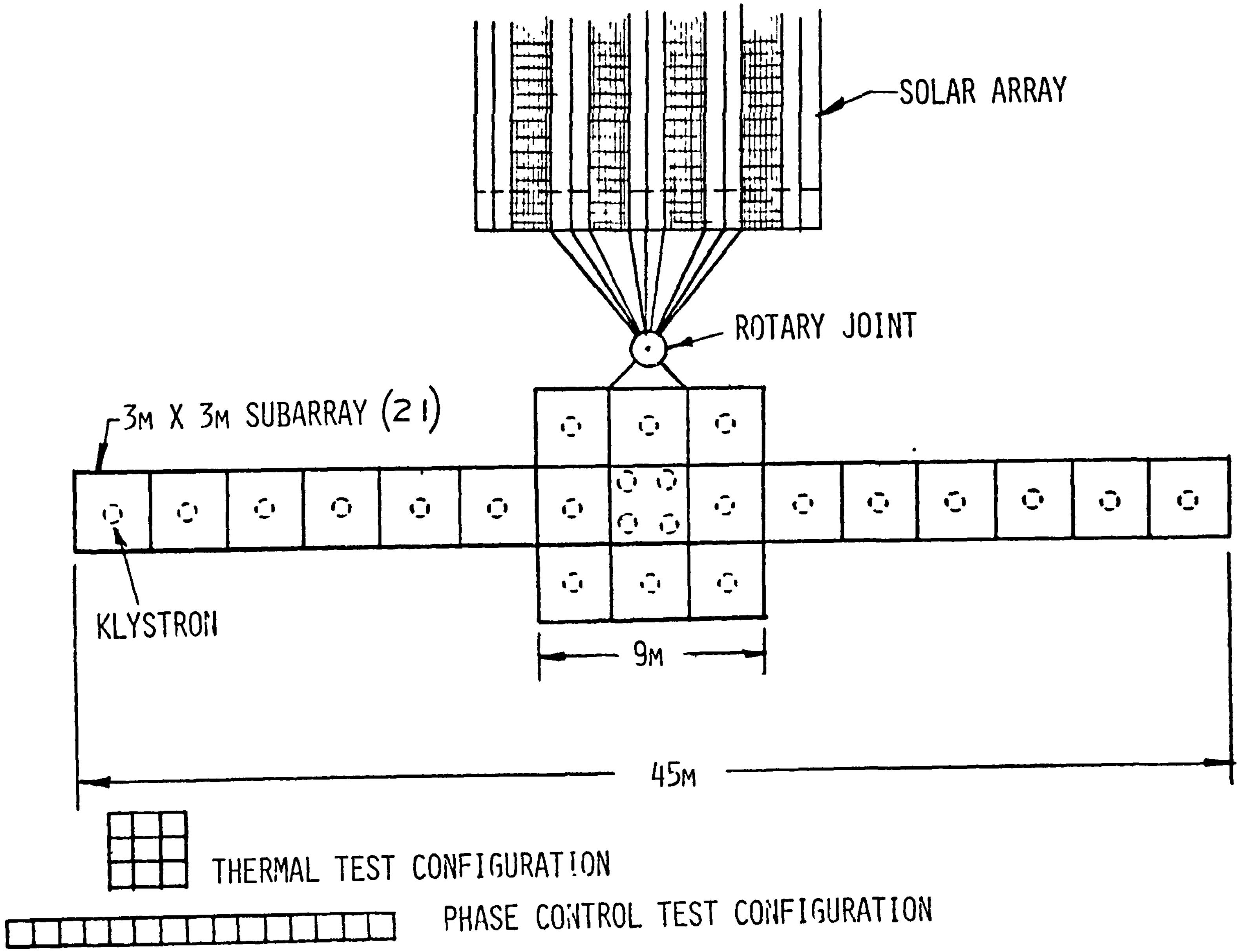
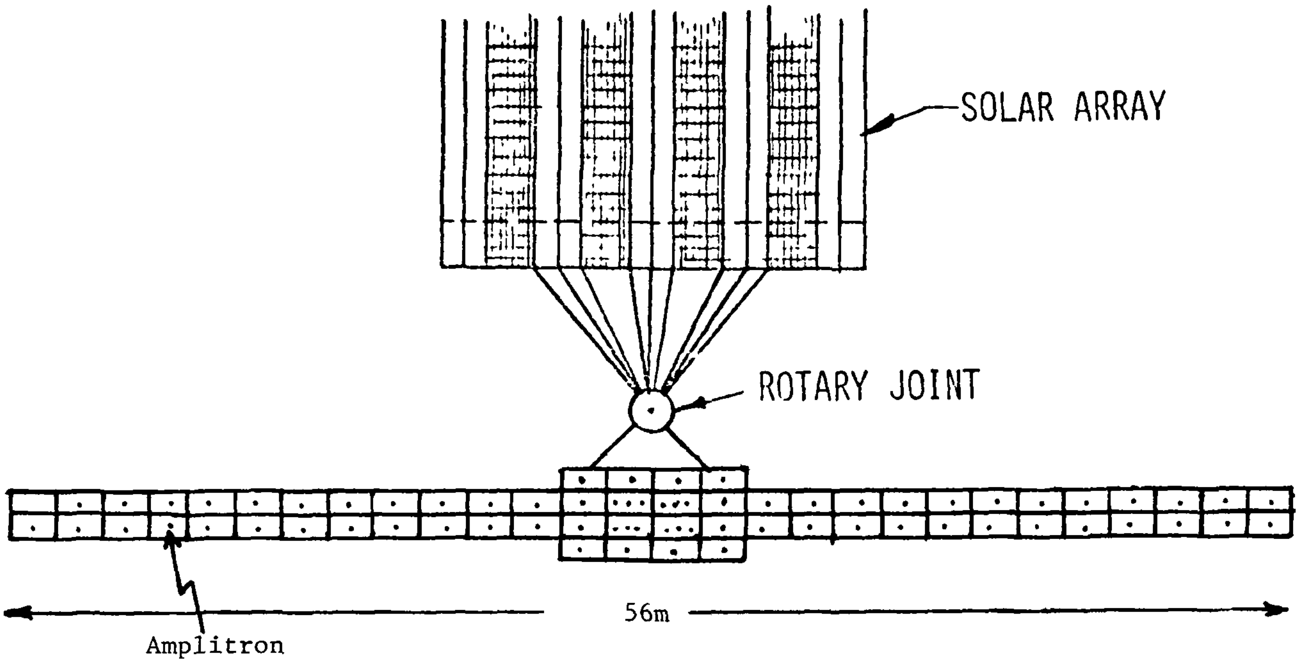
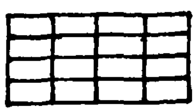


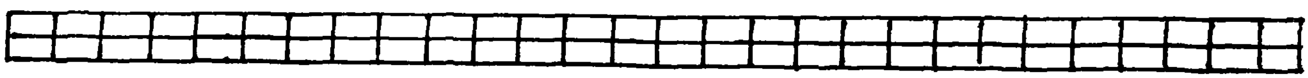
Figure IX-B-20 -Transmitting Antenna Using Amplitrons





Thermal Test Configuration

Phase Control Test Configuration



SYSTEM PARAMETERS

1. Solar array characteristics:

For sizing the microwave system, it is assumed that a shuttle construction base could build an entire solar array (structure, solar cell blankets, etc) with a $4000m^2$ area using one shuttle flight. The array shape is approximately 20 meters X 200 meters.

The DC power generated by the $4000 meter^2$ array is calculated assuming a 9.6% energy conversion efficiency refered to AMO (air mass zero) with a flux density of 1353 w/m^2; thus, the DC power generated per $meter^2$ of solar cell blanket is calculated to be 130 $watts/m^2$. Thus the total DC power generated by the 4000 m^2 solar array is 520 KW.

2. Microwave system efficiencies and power radiation:

The efficiencies within the experimental microwave system are assumed to be the same as for a full-scale SPS system. Those efficiencies pertinent to the test-configuration are

	solar array DC power distribution	antenna DC power distribution	phase control losses	waveguide losses	DC-RF power conversion
Efficiency =	.92 X	.98 X	.96 X	.99 X	.87

X .97 = .7158
mechanical alignment

The total available RF power within the antenna is

$$P_{RF} = P_{DC} \text{ X Eff} = (.7158)\ (520) = 372 \text{ KW}$$

3. Antenna characteristics using klystrons:

The antenna shall operate at the minimum power density (2.6 KW/m^2) and the maximum density (20.9 KW/m^2) as given for a representative full-scale SPS system (JSC report; #11442, Vol. II, pp IV.A.213). It is assumed that the high power (45-50KW) klystron tubes can operate at power levels reduced to about 23 KW while maintaining the full 87% DC-RF conversion efficiency. Since the total RF power available in the antenna is limited to 372 KW and the number of subarrays should be maximized for the phase control tests, the minimum power density subarrays will have only one klystron. The

subarray size is therefore

$$\text{Subarray area} = \frac{23 \text{ KW}}{2.6 \text{ KW/m}^2} = 8.8 \text{ m}^2$$

This subarray size must be compatible with one klystron feeding the .1225 meter slotted waveguides for the minimum density configuration and also be able to accommodate a maximum density configuration (where four 46 KW klystrons feed the subarray). Representative subarray layouts for these minimum and maximum density conditions are given in reference 1. The dimension for the subarrays equipped with klystrons is 2.94 m X 3.0 m.

The power radiated for the maximum density configuration is

$$P_{RF \text{ radiated}} = 8.8 \text{ m}^2 \text{ X } 20.9 \text{ KW/m}^2 = 184 \text{ KW}$$

which is provided by four 46 KW klystrons. These tubes have a 1.74 meter diameter passive thermal radiator attached on the backside of the subarray. The 2.94m X 3.0m subarray does have sufficient area to accommodate the four radiators.

For these phase control tests, the maximum density subarray will operate at 1/8 of its total power. Three of the four klystrons will be switched off; the fourth klystron will operate at 23 KW and will feed the entire subarray structure.

The uplink pilot beam phasing signal is received through the radiated slotted waveguides and then isolated by means of a diplexer and narrow-band filter from the downlink power beam.

The thermal distortion tests will operate in a configuration with the maximum density subarray surrounded by eight minimum density subarrays. The phase control tests will operate all subarrays at a minimum power density to maximize the number of phase control elements, i.e., subarrays. These configurations are shown in figure IX-B-19.

The total RF power radiated for the thermal distortion tests is

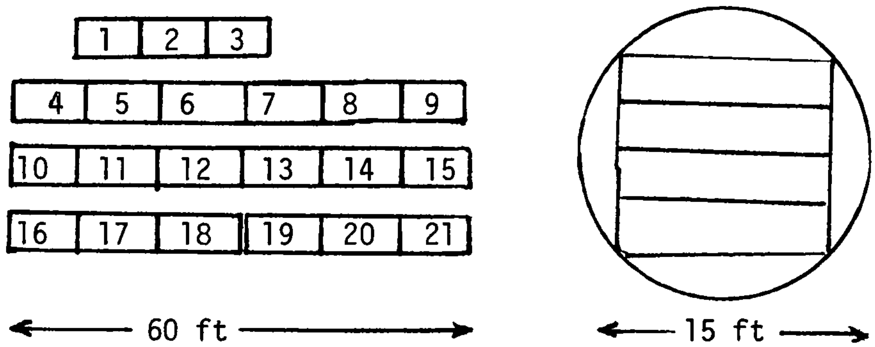
	center subarray		8 low-density subarrays
P_{TOTAL} =	184 KW	+	8 (23 KW/subarray) = 368 KW

Likewise the total RF power radiated for the phase control tests is

$$P_{TOTAL} = 23 \text{ KW/subarray X } 15 \text{ subarrays} - 345 \text{ KW}$$

The mechanical alignment requirement for the 3 meter subarrays is determine by the 3% loss allotted for off-axis gain. This loss corresponds to a $\pm$ 13 minute tilt for each subarray.

The antenna can be constructed on the ground with the power tubes attached to the structure and waveguides. It is then transported to low-earth orbit in one shuttle flight. One possible transport configuration is to divide the antenna



Transportation Configuration for Antenna with Klystrons

into five sections to be stowed in the 15 X 60 payload bay. It may be necessary to detach the three klystrons in subarrays 1, 2, and 3 to be compatible with the payload bay.

4. Antenna characteristics using amplitrons:

The subarray size for the amplitron-configured antenna has more constraints, due to differences in the feedguides between the tubes and the radiating antenna and to the differences in output power levels, i.e., 5 KW of radiating power and 1.25 KW of drive power for the next amplitron tube. The subarray size is determined by the maximu-density subarray configuration used in the thermal distortion tests. For the maximum density of 20.9 KW/m^2, the 5 KW of output power is radiated out through a .23 m^2 area of slotted waveguides. For a .1225 meter waveguide width, the corresponding length is 1.92 meters. Since the passive thermal radiators have a diameter of 48cm (reference 2), there will be a four-waveguide width under each 48cm thermal radiator. The subarray should therefore go in multiples of four amplitrons lengthwise. The reference subarray configuration using 5 KW amplitrons is .98 meter X 1.92 meters (see reference 1 for details). There are 8 amplitrons being driven in cascade for the maximum density subarrays.

There would be a cluster of four maximum density subarrays surrounded by twelve minimum density subarrays for the thermal distortion tests. For the phase control tests the four maximum

density subarrays could be reconfigured for minimum density by switching off seven of the amplitrons. The one remaining tube then feeds the entire subarray. The full 6.25 KW of RF power from the tube will be radiated through the slotted waveguides. Since the minimum density subarray has a 1.25 KW driver for each amplitron, there will be no cascading of the tubes. The power density for this subarray is

$$P_{density} = \frac{6.25 \text{ KW}}{1.92\text{m} \times .98\text{m}} = 3.32 \text{ KW/m}^2$$

which is slightly larger than the minimum density of 2.6KW/m^2 associated with the full SPS system.

The antenna configuration for the thermal distortion and phase control tests is shown in figure IX.B.2-3. The total RF power radiated for the thermal distortion tests is

$$P_{TOTAL} = 4 \overbrace{\left[8 \text{ Amp} \times 5 \text{ KW/Amp} + 1.25 \text{ KW (driver)}\right]}^{\text{4 center subarrays}}$$

$$+ 12 \overbrace{\left[5 \text{ KW/Amp} + 1.25 \text{ KW (driver)}\right]}^{\text{12 low-density subarrays}}$$

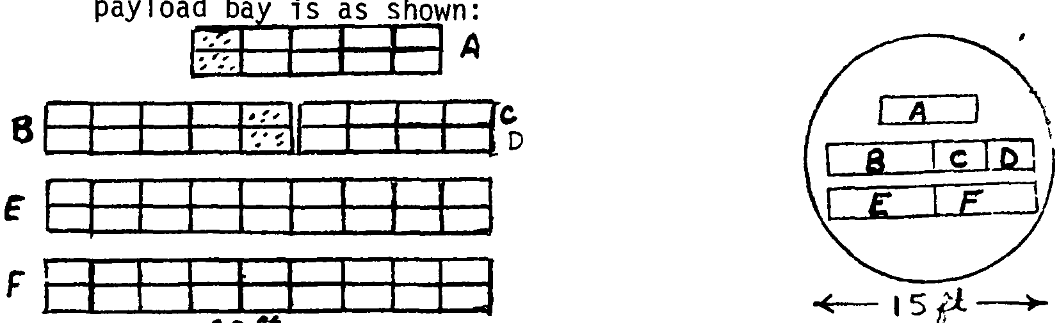
$$= 165 \text{ KW} + 75 \text{ KW} = 240 \text{ KW}$$

The total RF power radiated for the phase control tests is

$$P_{TOTAL} = 6.25 \text{ KW/subarray} \times 56 \text{ subarrays} = 350 \text{ KW}$$

The mechanical alignment for the 1.92 meter subarrays is determined by the 3% loss in off-axis gain, which corresponds to a $\pm$ 20.4 minute tilt for each subarray.

The entire microwave antenna can be constructed on the ground and transported into orbit with one shuttle flight. One possible packing configuration compatible with the 15 feet by 60 feet shuttle payload bay is as shown:



-Transportation Configuration for Antenna with Amplitrons

5. Receiving Satellites for Mapping Microwave Beam:

A separate satellite is used to provide the pilot signal to the transmit array and to map the resulting microwave beam. This mapping satellite, which has the same orbit plane as the transmit array, is located in the far-field of the antenna. This satellite can be a long, narrow boom with receiving elements at discrete increments for measuring the power levels or any combination of long booms attached together.

For the microwave antenna using klystrons where the maximum length is 45 meters (see figure IX-B-19), the Fresnel region distance is

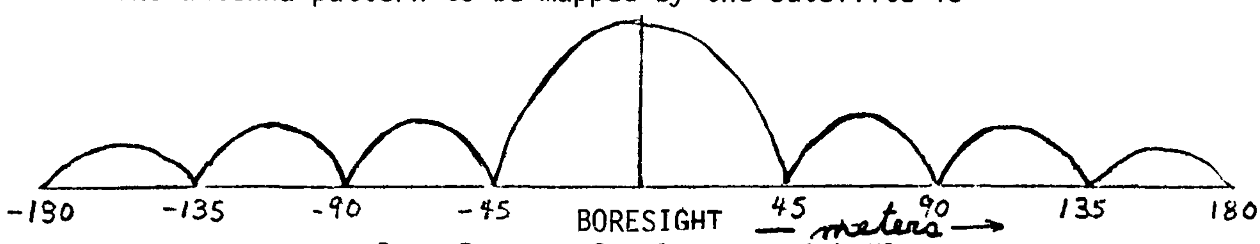
$$D^2/\lambda = (45)^2/.1225, \text{ or } 16,500 \text{ meters.}$$

The corresponding null points in the antenna pattern in the Fresnel region is λ/D radians, or $\frac{.1225}{45} \times 57.3 = .156$ degrees from boresight.

The radial distance from boresight to the first null, at a range of 16,500 meters from the antenna is, to the first approximation,

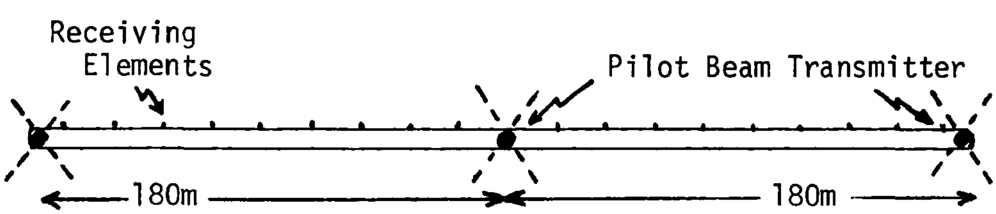
$$\text{radial distance} = \text{range} \times \theta \text{ null} = 16,500\text{m} \times \frac{.1225}{45} = 45 \text{ meters}$$

The antenna pattern to be mapped by the satellite is



Beam Pattern for Antenna with Klystrons

By having a long-boomed antenna with a pilot

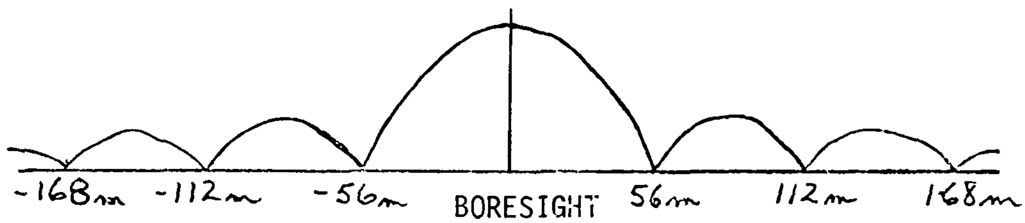


Beam Mapping Satellite for both the Klystron and Amplitron-configured Antenna

beam transmitter located at the center, the first three sidelobes can be mapped on both sides of boresight simultaneously. Activating a similar pilot beam transmitter at either end of the boom allows seven sidelobes to be mapped. This mapping should be sufficient

for ascertaining the performance of the phase control system.

For the antenna using amplitrons where the maximum length is 56 meters (see figure IX-B-20), the Fresnel distance is $(56)^2/.1225$ = 25,600 meters. The antenna pattern null point is $\frac{.1225}{56}$ X 57.3 = .125 degrees from boresight, and a corresponding distance of 25.600 X $\frac{.1225}{56}$ = 56 meters. The antenna pattern at a range of 25,600 meters is as shown:



Beam Pattern for Antenna with Amplitrons

The beam-mapping satellite shown in figure 12 will be able to measure a maximum of five sidelobes on either side of the main beam.

This satellite could be a conventional parabolic antenna with a diameter of 300 meters or greater, rather than a long boom. The microwave beam will be fan-shaped, with the narrow dimension perpendicular to the long axis of the transmit antenna. The additional receiving antenna area can provide information on the broadside of the beam.

6. Sizing Summary

In reviewing how the sizing of this LEO test article evolved, the constraints included: (1) for a klystron-configured antenna, operate at least one subarray at the maximum power density of 20.9 KW/m^2 (2) operate simultaneously, minimum-density subarrays (2.6 KW/m^2) surrounding the single maximum density array, and (3) assume the 46 KW klystron could still operate at maximum efficiency at the half-rated power level (23 KW). Therefore the subarray size is fixed at $8.8m^2$; the minimum density subarrays each radiate 23 KW of RF power; and the maximum density subarray radiates 184 KW, which is four fully-rated klystrons. The total RF radiated power is 368 KW for the thermal tests.

The phase-control tests maximize the number of individually-controlled subarrays in one dimension (direction). This allows maximum focusing of the beam at the space rectenna thereby providing the best sensitivity to phase errors and perturbations. The maximum number of subarrays should be an odd number to keep the antenna symmetrical with respect to the central subarray. Thus 15 minimum density subarrays radiating a total of 345 KW power is used for the phase control tests.

A similar antenna equipped with amplitrons was then designed to be compatible with the DC power available from the same solar array.

If it is desired to reduce the size and power of the LEO solar array and microwave system, a smaller klystron tube is needed. The output power rating of the klystron tube is the single most important sizing parameter, assuming the testing constraints given previously still apply.

IX. PROGRAM DEVELOPMENT PLAN

B. TECHNOLOGY ADVANCEMENT PLAN 1980-1987

3. Flight Activities

Louis Leopold
Tracking & Communications
Development Division

b. Flight Projects

(2) Alternative Concepts for Microwave Space Tests - The following microwave test descriptions are alternative concepts for accomplishing space testing of the microwave system.

(a) Low Earth Orbit LEO-LEO Transmission 25 kW RF Power Transmitted. This experiment would evaluate:

- o Arcing of DC-microwave converters
- o Arcing at tube-waveguide feed (20 kV and 40 kV levels)
- o Multipacting at the slots
- o Limited phase control testing in LEO to LEO transmission
- o Operation of amplitrons in LEO
- o Operation of 1 kW to 5 kW klystrons for LEO evaluation
- o Operation of 9x15 meter array (15 subarrays at 3m x 3m per subarray) limited phase control testing utilizing the 9x15 meter array
- o Antenna pattern tests in far field (4 km)

(b) Low Earth Orbit LEO-LEO Transmission 57 kW RF Power Transmission.

This would employ a crossed linear array antenna and could evaluate:

- o Leakage current at solar cells
- o Amplitrons in LEO
- o Low wattage klystrons in LEO
- o Arcing of tube at 20 and 40 kV in LEO
- o Antenna pattern verification
- o Verification of the theoretical sidelobe distribution predictions by means of LEO measurements. Sidelobe measurements would be performed on the horizontal array. The antenna is rotated around the yaw axis ±5° to allow

investigation of the antenna pattern out to the first subarray pattern sidelobe peak. The sensitivity of the antenna to power tube-induced temperature variations, mechanical distortions and sidelobe changes introduced by frequency changes (in the pilot or source frequency) would be measured. Also, sidelobe variations as a function of amplitron input voltage variations would be evaluated.

- o The dynamic retro-directive steering capability (pilot beam steering) of the crossed array.
- o RFI effects due to voltage level regulation and switching

(c) Low Earth Orbit LEO-LEO Transmission 440 kW RF Power Transmission

This will consist of a 9x15 meter array with 15 meter extensions attached to each end of the array as seen in Figure IX-B-21.

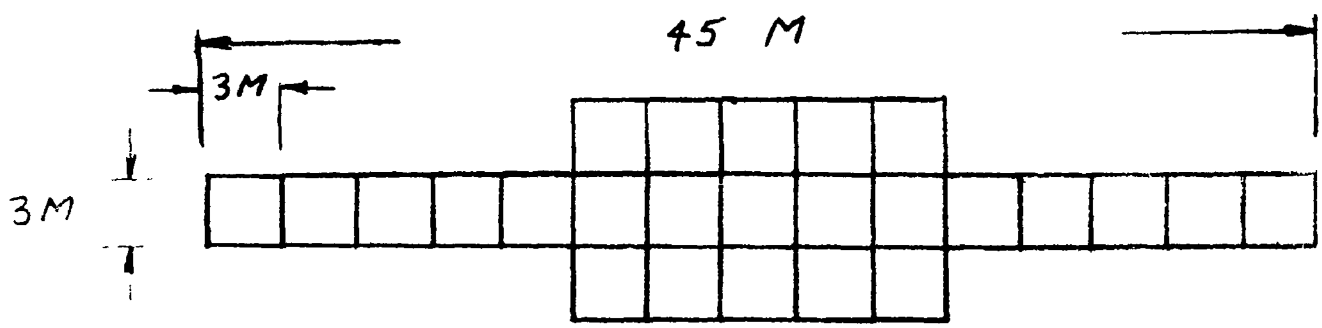


Figure IX-B-21

The 9X15 meter array (3x3 meter subarray) will transfer 440 kW of RF power to another receive satellite which will be located in the near field. The center subarray will radiate 21 kW per square meter for a total of 189 kW. The other 14 subarrays will each radiate approximately 2 kW per square meter adding up to 251 kW. This will produce 440 kW of RF power radiated under thermal conditions which simulate the SPS at GEO.

The configuration will also allow for 15 subarrays extending 45 meters to transmit during LEO-LEO. In this case, the power density will be 2 kW per square meter (15 subarrays) for a total radiated power of 270 kW.

The 45 meter array will be used for phase control and beam mapping in the far field. Grating and side lobes will be measured to determine possible effects on RFI as well as determine the efficiency of the SPS antenna.

Data for error sources and their distribution will supply required data to aid in the development of the SPS operational antenna at GEO.

The receiver will consist of a rectenna with the dimensions of 9x15 meters or larger. This antenna, when receiving in the near field, will collect approximately 99% of the RF energy.

(d) Low Earth Orbit LEO-Ground Transmission 440 kW RF Power Transmission

The same satellite 9x15 meter array which would transmit in LEO-LEO could be used to transmit from low earth orbit to earth. The function of this experiment would be to evaluate the phase control from low earth orbit to the earth's receiving station. A test of this type would also be a visible demonstration of power transmission from space to ground.

Using a rectenna on the ground to receive the power, a rectenna aperture diameter of 300 meters could receive approximately 310 watts from a 300 n.mi. altitude for a short period of time during close orbital passes. In addition, the possibility of using the Arecibo antenna as a receiver from LEO has been evaluated. The Arecibo dish of 100 meters diameter and a rectenna size of 45.7 meters in diameter at the receive feed could produce about 480 watts from a 300 n.mi. altitude. If the altitude during low earth orbit were 200 n.mi., the Arecibo antenna could receive about 1.2 kW.

(e) Geosynchronous Orbit GEO-Ground Transmission 57 kW RF Power Transmission

A similar crossed linear array which was first evaluated at LEO would be operated at GEO. The principal function is to verify the phase control capability from GEO to ground under the conditions of a heated ionosphere. This test would include a high frequency (HF) high power heating beam and a low power pilot signal (uplink) and a 57 kW (RF) beam of 2.45 GHz retro-directed (downlink). An HF ground based transmitter can provide the same heating effect as the 2.45 GHz, 5 GW SPS beam at GEO, but with less power. (power requirement scales inversely with frequency)

The pilot frequency, as yet undetermined, is generated on the ground near the rectenna. This will pass through the heated region and provide the means of "recording" the phase deformation imposed on passing wave-fronts. At the spaceborne transmitter, a retrodirective system uses this information to provide a downgoing beam with exactly the opposite deformation so that upon transit through the ionosphere the deformation is

removed and a compensated beam results. The retrodirective system provides automatic beam steering and always points at the pilot transmitter.

The crossed array would operate in the proper environment in which the operational SPS would later perform. This phase control signal is phase locked on the ground. The linear crossed array is commanded to slow roll and by means of optics the angular position of the array is correlated with the electrical signal received from the array. This process of beam steering will determine the errors created by ionospheric heating.

(3) Antenna Array-Subarray

The sizes of the subarrays for the tests being considered are 3m x 3m. The lengths of the crossed array will vary from 2.4m to 28.7m to produce a tapered beam. Except in the case of the crossed linear array, the subarrays will be attached to each other by flexible metallic supports and each subarray will be attached to its supporting structure at three points.

In the case of both the 25 kW and 57 kW antenna system candidates, there exists a solar array system peak load capability. With a 200 kW solar array power supply, the microwave system can use 100 kW DC for 75 minutes, or consume 300 kW DC for 17 minutes or 500 kW DC for 10 minutes in low earth orbit using a storage system + array for short power bursts.

Each subarray has a small antenna for receiving the pilot beam phasing signal.

Antenna Subarrays

Design of subarrays for the 9x15 meter array. LEO operation.

(a) Minimum power density subarray = 2.2 kW per square meter. The high efficiency power tube is an amplitron generating 5 kW RF. Each tube feeds 15 waveguides (10 cms wide) making up a 1.5m x 1.5m element. The slots are approximately 6 cms in length and spaced 6 cms apart.

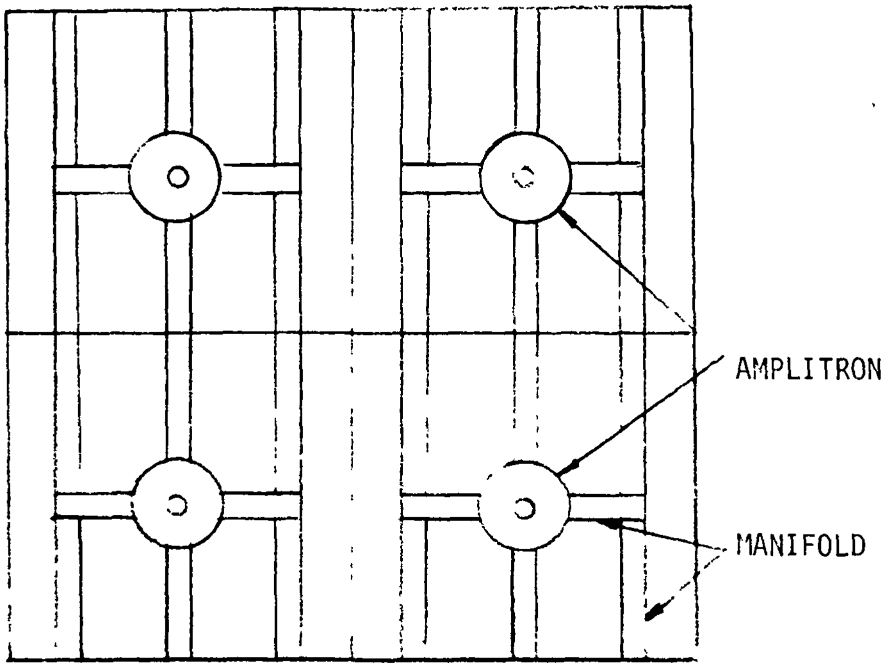


Figure IX-B-22: Minimum Power Density
Subarray with Amplitrons

(b) Minimum power density subarray = 2.2 kW per square meter. The tube is a 50 kW klystron operating at less than half power, 20 kW per tube. Each tube feeds 30 waveguides, 1 subarray.

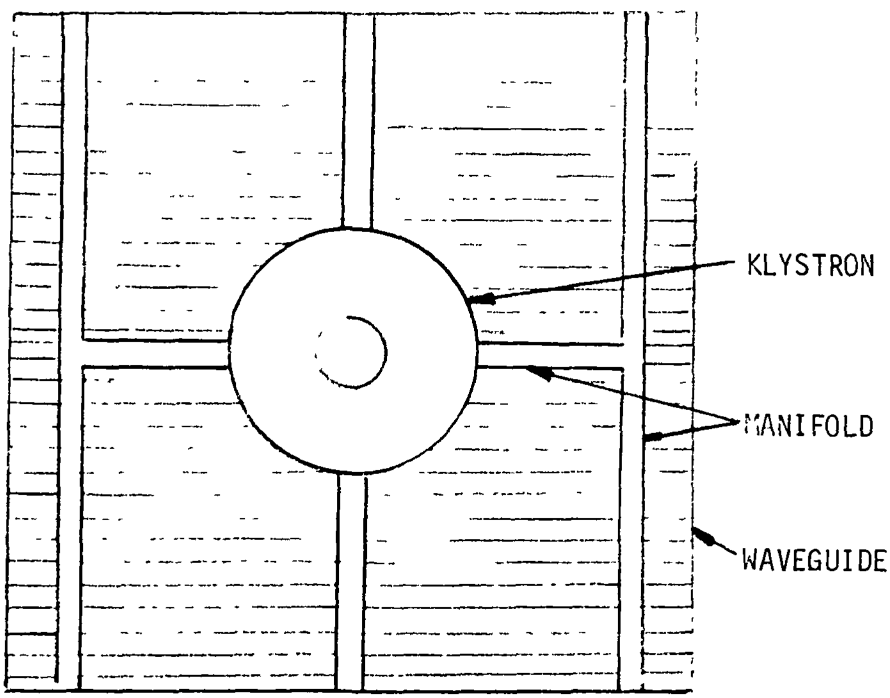


Figure IX-B-23: Minimum Power Density
Subarray with Klystron

(c) Maximum power density subarray = 20 kW per square meter. Amplitron feeds 5 waveguides, each section being 50 x 50 cms. Each subarray transmits 180 kW RF.

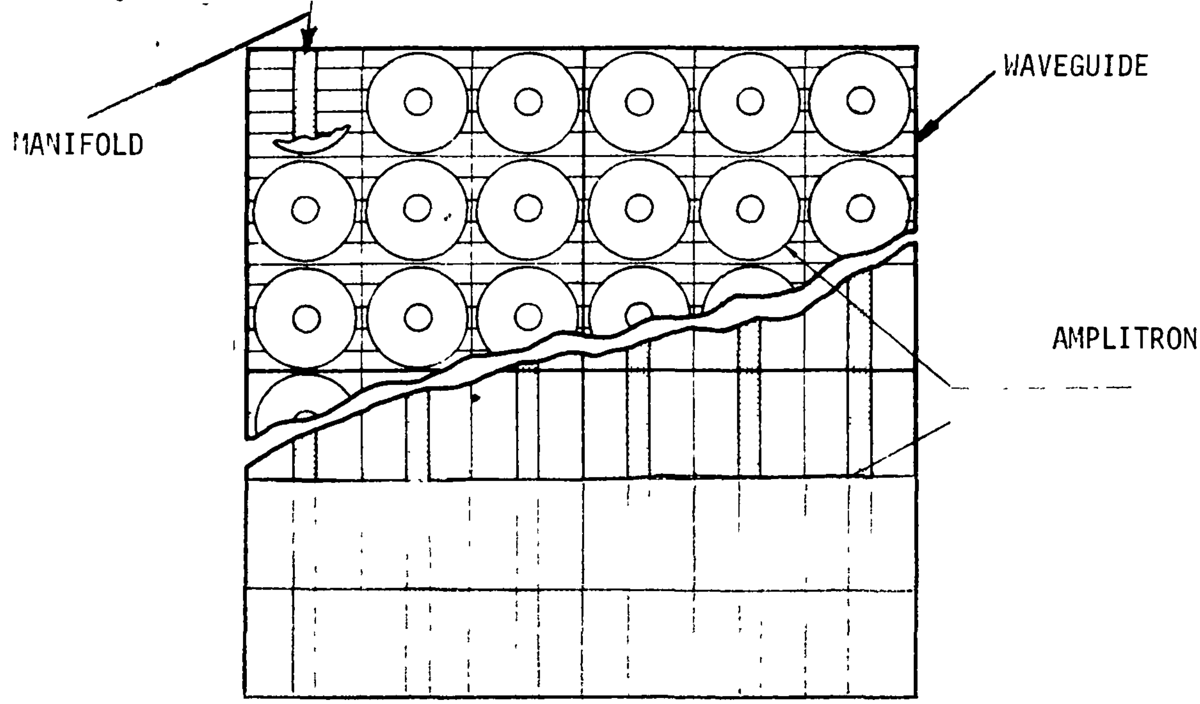


Figure IX-B-24: Maximum Power Density Subarray with Amplitrons

(d) Maximum power density subarray = 20 kW per square meter. Klystron feeds 15 waveguides. Each klystron generates 45 kW.

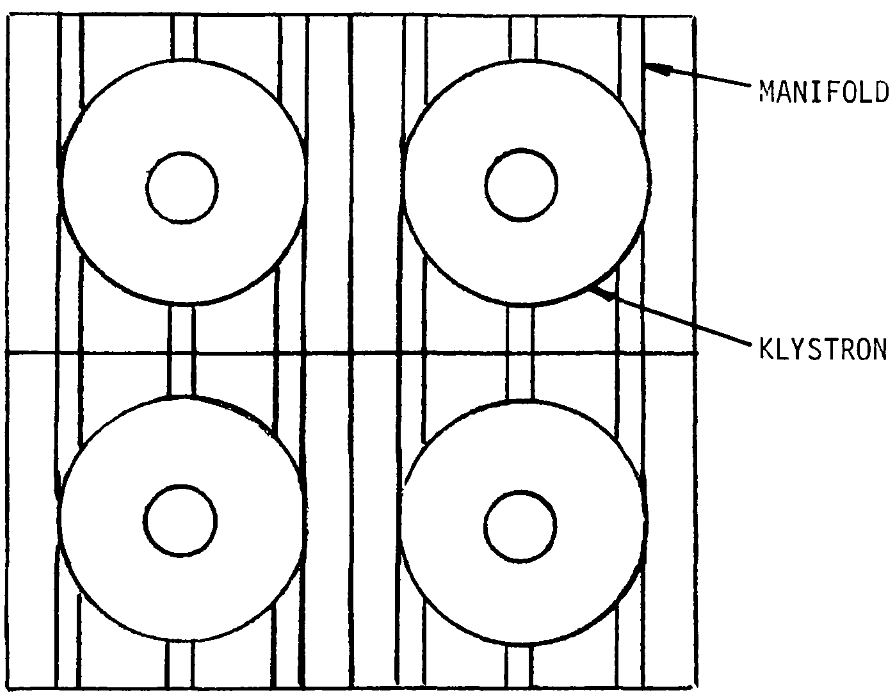


Figure IX-B-25: Maximum Power Density Subarray with Klystrons

R. C. Ried
Structures & Mechanics Div.

B. Technology Advancement Plan 1980-1987

3. Flight Activities

c. Scaling considerations for a structural test of the S.P.S. As currently envisioned, the SPS (Solar Power Satellite) structure will be designed for stiffness as required for maintaining shape and relative orientation. This can be achieved with efficient, lightweight structural concepts which are adequate for space application, yet not capable of supporting their own weight under terrestrial gravity. This precludes ground testing and points to the need for space testing for structural performance, fabrication precision, control/structure interactions and potential* thermal/structural interactions. Although geo-synchronous orbit (GSO, designated by subscript G) is unique from the standpoint of the overall system kinematics and power transmission, it appears that low earth orbit (LEO, designated by subscript L) offers many significant advantages for a scale model structural test of the system and/or its components. The basic objective of a scale model structural test would be to verify our capability to analytically predict the structural performance of the scale model system and, thereby, the full-scale SPS structure and associated systems. A scale model test in LEO should be preceeded by numerous small component tests (compression elements, cables, joints, assemblies, subarrays, etc.) as required to build our level of understanding and confidence. The engineering confidence obtained through a scale model test will be proportional to the degree of similitude achieved. The following treatment of various scaling relations and practical considerations is not a rigorous similitude analysis, but rather a point of departure for trading structural test considerations against other system test requirements. Table IX-B-2 summarizes a scale test approach and general scale system characteristics.

EXCITATION FREQUENCIES

Most of the SPS excitations and interactions occur with a frequency which is proportional to the orbital frequency or angular velocity (ω). This includes gravity gradient, rotary joint cycles, MPTS/solar cycle, orbital perterbations and magnetic field fluctuations. Due to an orbital balance of centrifugal and gravitational acceleration, the angular velocity is related to the orbital radius (r) by

$$\omega \sim r^{-3/2}$$

Since the earth's radius is 6.4×10^3 km and r_G is 42×10^3 km, the angular velocity or orbital frequency ratio for three LEO altitudes are:

---

*A design approach to minimize thermal/structural interactions would be the use of materials and/or geometric arrangements which virtually eliminate thermal distortions.

$$s \equiv \frac{\omega_L}{\omega_G} = \begin{array}{l} 16.2 \text{ for } 200 \text{ Km } (108 \text{ n mi}) \\ 15 \quad \text{for } 500 \text{ Km } (270 \text{ n mi}) \\ 13.6 \text{ for } 1000 \text{ Km } (540 \text{ n mi}) \end{array}$$

For discussion and numerical simplicity, events in LEO are about 15 times faster than at GSO.

CONTROL SYSTEM

The control system logic and update or correction frequencies are yet to be determined; however, it is logical to assume that a control system in LEO will operate s times faster than in GSO for the same angular orientation requirements. Angular orientations are dimensionless and will be assumed to be the same for a scale model test as for the full scale SPS. In addition, the control system technology development requirements for the SPS are in the direction of low frequencies and, therefore, a faster system seems reasonable for an earlier scale model test.

STRUCTURAL NATURAL FREQUENCIES

Antenna Structure:

By equating the maximum kinetic energy to the maximum potential energy of a uniform free circular plate undergoing a harmonic oscillation, the plate natural frequency (η) can be derived

$$\eta \simeq \frac{5.3}{R} \left(\frac{h}{R}\right) \sqrt{\frac{Eh}{12 \ \beta \ (1-\nu^2)}}$$

where:

R is the circular plate radius
h is the circular plate thickness
E is Young's modulus of the plate material
β is the mass per unit area of the plate
ν is Poisson's ratio for the plate material

The SPS antenna can be modeled in a similar fashion by properly accounting for the potential energy associated with a primary structure deformation. The resulting MPTS structural natural frequency (η_A) can be expressed

$$\eta_A = \frac{5.3}{R} \left(\frac{h}{R}\right) \sqrt{\frac{1}{2} \left(\frac{E}{\rho}\right) \frac{2}{5} \frac{\beta_S}{\beta_T} \frac{1}{(1-\nu'^2)}}$$

where:

$\left(\frac{E}{\rho}\right)$ is the Young's modulus to mass density ratio of the structural material (material specific potential strain energy)

$$\frac{\beta_S}{\beta_T} = \frac{\text{prime structural mass/unit area}}{\text{total system mass/unit area}} \sim .02$$

$(\frac{2}{5})$ is a prime structure mass factor for a tetrahedral planer truss (structural mass in top or bottom surface/total prime structural mass, neglecting joints and diagonals)

ν' is the Poisson ratio for the truss arrangement.

This relation assumes a circular antenna with a uniform mass distribution (no taper). Note that for a given structural material the natural frequency is controlled by the geometry and the mass fraction, not the absolute mass.

Assuming the structural frequencies to be one order of magnitude above the control correction or excitation frequencies and a compliant control system,

$$\frac{\eta_{A})_L}{\eta_{A})_G} = \frac{\omega_L}{\omega_G} = s$$

or

$$\frac{\frac{1}{R}\frac{h}{R}\sqrt{\left(\frac{E}{\rho}\frac{\beta_s}{\beta_T}\right)_L}}{\frac{1}{R}\frac{h}{R}\sqrt{\left(\frac{E}{\rho}\frac{\beta_s}{\beta_T}\right)_G}} = s$$

If one assumes the same structural material (E/ρ), geometric similarity $(h/R)_L = h/R)_G)$ and similar mass fractions, then

$$R_L = \frac{R_G}{s} \simeq \frac{R_G}{15} \simeq 33 \text{ m}$$

If full scale hardware (waveguides, Klystrons or Amplitrons, etc.) are employed, the scale model antenna mass is on the order of 3×10^4 kg or the equivalent of one Shuttle payload. On the other hand, a non-operating lower mass per unit area system would suffice for this simulation alone. It should be noted that our current reference MPTS structural system contains secondary structures which are roughly 1/8 scale prime structures. A 1/15 scale prime structure with 140, 5 meter subarrays mounted on it would be somewhat similar to a portion of the full scale system. It might be possible to devise a test arrangement where the same test model could be used, both as a scale test of the full scale system, and also as a component test of the full scale system.*

---

*A scale subarray waveguide system would require s times higher frequency or 36.8 GHZ and suitably scaled microwave amplifiers. This would entail considerable hardware development effort and many practical problems; however, if such a system were possible it would provide a significant power beam from GSO.

C-10

Photovoltaic Array Structure:

The truss structure for the photovoltaic array can be modeled as a beam such that the natural frequency of the structural system (η_S) is:

$$\eta_S = \frac{3.6}{L^2}\sqrt{\frac{EI}{\beta_T w}}$$

where:

L is the maximum length of the beam
E is Young's modulus
I is the beam moment of inertia
β_T is the system mass per unit area
w is the width of the beam

Inserting the proper moment of inertia of our reference truss configuration, this can be expressed in the form

$$\eta_S \simeq \frac{1}{6L}\left(\frac{h}{L}\right)\sqrt{\left(\frac{E}{\rho}\right)\frac{\beta_S}{\beta_T}}\ ^*$$

where:

h is the depth of the truss

$$\frac{\beta_S}{\beta_T} = \frac{\text{prime structure mass/unit area}}{\text{total system mass/unit area}} \sim .05$$

The scaling logic for the photovoltaic array structure follows precisely the same logic as the antenna. A 1/15 scale system in LEO would be desirable. The total system mass (assume full scale hardware or the same mass per unit area) would be on the order of 3.5×10^5 kg or about twelve Shuttle payloads. It would have a length of about 1.8 km ($\sim$ 1 n mi) and would be rated as a 45 MW bus bar system.

Blanket Structure:

The column cable system would follow a similar scaling ratio for frequency simulation; however, the natural frequency of a membrane or cable depends on the stress level as opposed to Young's modulus. Specifically, the natural frequency of a membrane such as a solar cell blanket or reflector is

---

*It should be noted that a tetrahedral truss structure would have a 40 percent higher frequency (considering only bending) for about half the structural weight, but this would not readily accommodate a two-to-one concentration ratio.

$$\eta_B \sim \frac{1}{\ell}\sqrt{\frac{\sigma_S}{\rho_S}\frac{\beta_S}{\beta_B}}$$

where:

η_B is the blanket system natural frequency

ℓ is a characteristic length of the blanket

σ_S is the stress in the blanket structural substrate

ρ_S is the mass density of the structural substrate material

β_S is the structural substrate mass per unit area

β_B is the total blanket mass per unit area

Note that the same linear scaling applies to the solar cell blankets, reflectors, and cables whether they are elements of the truss configuration or the long expanses of the column cable configuration.

It should also be noted that the blanket membrane tension must be sufficient to overcome the natural environment (eg. gravity gradient), as well as control system corrections, but the structure must be even stiffer to restrain the blanket dynamics. The structure plays the role of a mast supporting a sail.

The main significance of the membrane tension aspect of scale modeling of the SPS is that the full scale SPS is incorporating minimum gauge structural substrate support of the blankets. Thus, although the natural frequencies involve only the ratio of structural mass to total mass, one is forced to use full scale mass per unit areas or to accept void areas.

STRUCTURAL GEOMETRY

In consideration of frequency scaling, one is led to global geometric similitude and numerically equal mass per unit areas. This is inconsistent for the structural members per se since the structural mass under geometric similitude should scale as the volume or length cubed. If, however, the structural gauge is maintained constant then the structural mass per unit area will be constant. This is consistent with minimum gauge structure, blanket substrates, reflectors, waveguides and much of the SPS hardware. It does not alter the structural member natural frequencies or column buckling margins, but it does afford a considerable margin for crimpling or local buckling. It is recommended that structural member lengths and widths (or diameters) be scaled, but the gauge or thickness remain constant. To maintain the same stress per structural member (for similar strains and buckling margins) implies the force per member be reduced by the scale factor (s). Since the number of members is unchanged by geometric similitude, all forces should be reduced by the scale factor s(15). This implies that all moments should be reduced by the square of the scale factor (s^2 or 225).

GRAVITY GRADIENT TORQUES

For a given orientation, the gravity gradient torque is proportional to the differences in moments of inertia and inversely proportional to

the cube of the orbit radius. Thus,

$$\frac{N_L}{N_G} = \frac{\beta_L R_L^4 / r_L^3}{\beta_G R_G^4 / r_G^3} = \frac{1}{s^2} \text{ for scaling}$$

where:

N is the gravity gradient torque
β is the mass per unit area of the system
R is a characteristic dimension of the system
s is the scale factor (15)

Since

$$\left(\frac{r_G}{r_L}\right)^3 = s^2$$

and

$$\left(\frac{R_L}{R_G}\right)^4 = \frac{1}{s^4}$$

scaling is satisfied for gravity gradient torques, given global geometric similitude and constant masses per unit areas. The applied control forces to overcome gravity gradient torques on the scale model test would be 1/15 of the full scale SPS control system.

CURRENT INTERACTION FORCES

The forces between conductors, which are most significant in the vicinity of the joint, are proportional to the square of the current and inversely proportional to the distance between conductors. Scaling is maintained if the currents (i) are proportional to the scale factor

$$\frac{i_L}{i_G} = \frac{1}{s} = \frac{1}{15}$$

therefore,

$$\frac{i_L^2 R_G}{i_G^2 R_L} = \frac{1}{s}$$

Since the power (voltage times current) is proportional to the system area, the voltage (V) is also proportional to the scale factor

$$\frac{V_L}{V_G} = \frac{1}{s} \approx \text{eg. } \frac{2{,}700 \text{ volts}}{40{,}000 \text{ volts}}$$

This structural requirement has the advantage of lower operating voltages in LEO and the potential for a geometrically similar wiring pattern. If the power distribution conductors are scaled in the same fashion as the structural members, (1/15 length, 1/15 width or diameter, thickness or gauge is held constant and the same material is used) then scaling is maintained in these conductors. They operate at full scale current densities, have a full scale resistivity (ρ_c) and generate the same heat per unit surface area.

$$\rho_c = \frac{\text{voltage drop X cross sectional area}}{\text{current X conductor length}}$$

$$\frac{\rho_c)_L}{\rho_c)_G} = \frac{\frac{1}{s} \times \frac{1}{s}}{\frac{1}{s} \times \frac{1}{s}} = 1$$

The conductor resistance (R_C) is the same for the scale model as for the full scale system

$$R_c = \frac{\rho_c \text{ X length}}{\text{cross sectional area}}$$

The resistance losses for the conductors are in the same proportion as the system power,

$$\left.\frac{i^2 R_c}{V\, i}\right)_L = \left.\frac{i^2 R_c}{V\, i}\right)_G$$

Also, since the resistance losses for the conductors per unit of conductor surface area is the same for the scale model as for the full scale SPS, they would both operate at the same temperature. This is a significant point since thermal control of the power distribution system is an important aspect of that system.

MAGNETIC LOOP TORQUES

Current loops on the SPS could interact with the earth's magnetic field and potentially produce torques about two axis (not the North-South axis or field lines). Assuming the earth's magnetic field to be represented by a single dipole, a magnetic loop torque (M) ratio is

$$\frac{M_L}{M_G} = \frac{i_L R_L^2}{i_G R_G^2} \frac{r_G^3}{r_L^3} = \frac{1}{s}$$

where R is a characteristic system dimension.

This is inconsistent with the proposed scaling. Moments and torques should be proportional to the scale factor squared. Thus, magnetic loop torques would be more powerful for the scale model test in LEO than to the full scale SPS in GSO.

SOLAR PRESSURE

The solar pressure is the same in LEO and in GSO. Since the proposed scaling involves equal mass per unit area, the potential acceleration due to solar pressure is the same for both the scale model and the full scale system. This is not consistent with the proposed scaling where acceleration (a) should scale such that

$$\frac{a_L}{a_G} \sim \frac{\left.\frac{E}{\rho}\right)_L R_G}{\left.\frac{E}{\rho}\right)_G R_L} = s$$

Also, the force in a given structural member due to solar pressure on the scale model would be $1/s^2$ times the full scale system as opposed to the desired $1/s$.

AERODYNAMIC DRAG

Aerodynamic drag is virtually zero in GSO; however, in LEO it is a significant factor in orbital decay. If one flew a scale model SPS in the worst orientation (into the wind), it would experience decelerations of roughly 4×10^{-3} g's and 10^{-5} g's at altitudes of 200 km and 500 km, respectively. These do not appear to be prohibitive since the scale model can withstand a scale factor (15) times the maximum acceleration capability of the full scale SPS. For reference, the MPTS axial acceleration, which would completely consume the 10^{-4} radian mechanical distortion budget, is only 6×10^{-3} g's for the full scale SPS and 9×10^{-2} g's for the scale model.

Since the solar radiation pressure does not follow an appropriate scale up for a LEO test, one could conceive of an experiment where the aerodynamic pressure was used to simulate a scaled up solar pressure. This could be performed by flying the solar array into the wind at approximately 400 km altitude.

ACHIEVABLE FLATNESS

The factors governing achievable flatness for an SPS antenna structure, either through construction, assembly or deployment, have yet to be studied. Intuitively, one can visualize full scale components being used for a verification of achievable flatness; however, this might well be independent of a scale model test.

DAMPING

Structural and overall system damping characteristics have yet to be studied for both the full scale SPS and for desired scaling characteristics.

An isometric stress imposed to reduce joint "slop" and associated non-linear deflection characteristics would tend to minimize the damping associated with joints.

THERMAL/STRUCTURAL INTERACTION

The thermal/structural interactions in a scale model LEO test affords an excellent opportunity to verify analysis capability for temperature levels, temperature distributions, thermal distortions and transient behavior. For structural scaling, one would desire each scale model structural member to operate at the same temperature and temperature distribution as its full scale counterpart. Also, it would be desirable to have thermal transients occur a scale factor (s) faster.

In GSO, the thermal environment consists of thermal radiation from the sun and from waste heat rejection. In LEO, the earth's albedo (up to 36 percent of the solar flux) and the earth's thermal emission (17 percent of the solar flux, but in the infrared) are also significant. The resulting temperatures in LEO and GSO depend on relative orientations and surface properties; however, as a general rule, the differences are small for the higher temperature structures (center of antenna where waste heat dominates) and greatest for the low temperature extremes (LEO night > GSO eclipse). For example, for an antenna pointed away from earth, a structural member (α_S/ε = .1) in the center of the antenna which operated at 450°K (350°F) in GSO would reach about 466°K (380°F) in LEO. During an eclipse at GSO, however, this member would drop to a temperature as low as 100°K (-280°F), while in LEO the earth's emission would maintain this member above 250°K (-10°F). On the other hand, for an antenna pointed to the earth, this structural member would achieve a reasonable thermal simulation.

The full scale MPTS has a potential for thermal distortion of the prime structure as a result of its daily rotation relative to the sun. The angular distortion or warping, due to a temperature difference through the depth of the prime structure, is

$$\theta \approx 2\,\alpha\,\Delta\,T\,\left(\frac{R}{h}\right) \leq 10^{-4} \text{ radians}$$

where:

- θ is the angular distortion
- α is the coefficient of thermal expansion for the prime structure members
- ΔT is the temperature difference between the front and back prime structure member relative to the temperatures associated with a flat antenna
- R/h is the radius to depth ratio of the antenna prime structure

It should be noted that for $\alpha \approx 10^{-6}$/°K (typical of graphite composite without preferential orientation) the allowable temperature difference ΔT is less than 10°K. On the other hand, if the α is reduced by an order of magnitude through preferential ply orientation or alternate techniques,

then, the allowable temperature difference increases proportionately. This distortion is readily scaled in an LEO test by the use of geometric similarity, full scale materials and comparable temperature differences (solar orientations).

The thermal distortion simulation of individual structural members requires geometric similarity, the same material (coefficient of thermal expansion, emissivity, absortivity, conductivity, density and specific heat) and a similar environment. This is probably best achieved through full scale component testing to obtain data on all types of distortion. The significance of an LEO scale model which incorporates full scale gauge material depends on the element configuration. If the structural element is relatively open or essentially opaque to thermal radiation, then the increased relative importance of conduction will not be significant for the scale model structural element.

The characteristic time governing the initial cool down rate for a structural member as it undergoes an eclipse is

$$\frac{\rho\ C_p\ t}{3\ \varepsilon\ \sigma\ T_o^3}$$

where:

ρ is the material density

C_p is the material specific heat

t is the material thickness

σ is the Stephan-Boltzmann constant

T_o is the initial temperature

ε is the surface emittance

Therefore, the LEO scale model test and the full scale SPS structural members will have the same characteristic thermal response times (about 10 minutes for graphite composite, 10 mil thick, $\varepsilon = .85$). It would be desirable to have a scale factor (s) faster thermal response time to simulate potential dynamic motions associated with cooling down or warming up. The penumbra passage is about 18 times faster in LEO than in GEO; therefore, the onset and termination of an eclipse is reasonably well simulated.

If thermal/structural coupling is not virtually eliminated by selective basic structural elements, then it is possible that the antenna would be built in a cold warped form which would flatten out as the system is powered up. This could also be simulated in a scale test for verification of the technique.

MEASUREMENT

The measurement of structural performance in a scale model test is an area which remains to be investigated. It is noted, however, that a determination of overall system performance, although not sufficient, is a necessary measurement. For example, a proper focusing of the microwave beam and efficient power transmission requires an acceptable MPTS structural performance.

Table IX-B-2

Scaling Factors for Scale Model LEO
Structural Test of GSO SPS (s ∿ 15)

Parameter	GSO / LEO	Comments on Scale Model
Configuration		
length	s	∿ 1.8 km (1 n mi)
width	s	66 m diameter antenna
depth	s	
Mass	s^2	∿ 3.5 X 10^5 kg (12 Shuttle payloads)
Mass/surface area	1	full scale hardware eg. solar cells
Power	s^2	∿ 1/225
Power Distribution System		
lengths	s	
widths (or diameter)	s	
thickness	1	
voltage	s	∿ 2,700 volts
current	s	
resistance	1	
operating temperature	∿1	
Structural Members		
length	s	} similar buckling criteria
width or diameter	s	
thickness	1	minimum gauge
stress	1	
strain	1	
angular distortion	1	
E/ρ	1	same material
Excitation Frequencies	1/s	relative to orbital frequencies
Control Frequencies	1/s	
Natural Frequencies		
Structure		
antenna	1/s	
truss	1/s	
col/cable	1/s	
Array	1/s	
Forces (s desired)		
control	s	
gravity gradient	s	

current interactions	s		
solar radiation	s^2	X	Does not scale appropriately
aerodynamic drag	$\sim 10^{-20}$	X	Does not scale appropriately but might be used to simulate solar radiation
Moments (s^2 desired)			
control	s^2		
gravity gradient	s^2		
magnetic loop interaction	s	X	Does not scale appropriately
Accelerations			
linear	1/s		
angular	$1/s^2$		
Thermal			
high temperatures	$\sim$1-.8		
low temperatures	$\sim$1-.3		
penumbra transit time	1.2s		
characteristic thermal response time	$\sim$1	X	Does not scale appropriately
Achievable Flatness	?		
Damping	?		
Measurement	?		

IX. PROGRAM DEVELOPMENT PLAN

B. TECHNOLOGY ADVANCEMENT PLAN

IX-B-4. Space Transportation

H. P. Davis
Future Programs Office

The purpose of the space transportation technology plan is to outline the advanced technology for the overall system, subsystem and mission planning technology required for the Solar Power Satellite transportation systems. The space transportation system is comprised of two major elements: the heavy lift launch vehicle (HLLV) and the orbital transfer vehicle (OTV). The objective and tasks for the HLLV and the OTV are as follows:

1. Primary HLLV Definition

Objectives

o Select primary launch vehicle configuration utilizing advanced technology and entailing a moderate level of uncertainty of program schedule and cost.

o Develop preliminary level II HLLV program definition and requirements documentation.

Tasks

o Survey technology capabilities expected in the 1980's development period, rate potential and feasibility and determine the launch vehicle technology levels to be used for primary HLLV conceptual planning.

o Select primary HLLV configuration concept based on parametric study of options and selection criteria.

o Define selected primary HLLV configuration, fleet size, inventory, GSE and launch facility requirements.

o Prepare development and programmatic plans.

o Prepare the preliminary HLLV level II Program Definition and Requirements Document.

2. Backup HLLV Definition

Objectives

o Select backup launch vehicle configuration for level I requirements utilizing current or assured near-term technology to minimize the uncertainties of program schedule and costs.

o Develop preliminary level II HLLV program definition and requirements documentation.

Tasks

o Survey technology capabilities expected in the 1980's development period, rate potential and feasibility and determine the launch vehicle technology levels to be used for backup HLLV conceptual planning.

o Select backup HLLV configuration concept (based on parametric study of options and selection criteria).

o Define selected backup HLLV configuration, fleet size, inventory, GSE and launch facility requirements.

o Prepare development and programmatic plans.

o Prepare the preliminary backup HLLV level II Program Definition and Requirements Document.

3. Personnel/High Priority Cargo Launch Vehicle Requirements Definition (Shuttle Derivative)

Objectives

o Define the possible evolutionary growth paths of the Space Shuttle system to provide the transportation of personnel and high priority cargo to LEO, the capability of return to Earth of selected SPS operational program hardware, and to support the orbital technology verification and potential subscale "pilot plant" projects.

Tasks

o Conduct study to determine what SPS operational requirements may be fulfilled by (1) the STS, (2) uprated STS, and (3) STS derived launch vehicles more cost effectively than baselined HLLV.

o Define preliminary design requirements and mission models for candidate systems.

o Define design requirements, mission model and programmatic requirements for personnel and high priority cargo launch vehicle based upon STS.

4. Flight and Ground Operations Definition

Objectives

o Develop operational program requirements.

o Identify programmatic issues and requirements.

Tasks

o Determine operational requirements for ground and flight activities supporting the transportation requirements of the power station including its operation, maintenance and servicing.

o Analyze organization and managerial requirements, identify present capability and delta requirements, and recommend new or evolutionary concepts.

o Prepare program plan for acquiring necessary flight and ground operations capability with schedule and costing requirements identified.

5. Launch Vehicle Environmental Effects Data Development

Objectives

o Determine the altitude profile (quantity, species, velocity) of exhaust emissions consequent to launch vehicle operations, the launch vehicle projects consumption of terrestrial energy and consumption of scarce materials for each candidate HLLV and Shuttle-derived launch vehicle. These data will be provided to the environmental Effects Area for impact assessment and analysis.

Tasks

o Develop computer program to obtain altitude profile of exhaust emissions (quantity, species, velocity) for launch vehicles under consideration.

o Develop data bank of energy requirements for materials production and fabrication.

o Establish scarce materials roster and procedures for recording and analyzing usage by launch vehicle configuration concepts under evaluation.

o Document results of exhaust emission, energy and materials procedures in launch evaluation process.

6. OTV Supporting Research and Technology

Objectives

o Develop new propulsion technologies and hardware, software, and system elements in support of all OTV design activities.

Tasks

o Develop and test an electric-thruster meeting performance and program requirements suitable for incorporation into the primary OTV low thrust propulsion system.

o Develop a control system and associated software capable of supporting the primary OTV low thrust propulsion system and operational or interface limitations of the SPS.

o Develop on-orbit basing techniques for high thrust OTV. This includes on-orbit fueling, refurbishment, maintenance, inspection, and turnaround.

o Define the beneficial influence of advanced technology on the elements of the manned OTV crew modules/compartments.

7. Orbital Transfer Vehicle Requipments

Objectives

o Establish preliminary OTV performance and programmatic requirements.

o Integrate, expand, and revise these requirements as required throughout the OTV design activities.

Tasks

o For both low thrust and high thrust propulsion systems, establish the following:

- SPS orbital transfer performance requirements, including maximum thrust limitations, thrust profiles, thrust distribution and vectoring, and SPS mass and C. G. characteristics, including active stabilization needs.
- Subsystem support available from the SPS payload element to the OTV's.
- SPS interfaces, including hardware, software, functional and operational factors
- GSE requirements
- Vehicle and propellant safety and environmental compatibility.
- Operational requirements and constraints.
- Develop parametric systems data on high and low thrust propulsion systems for manned and unmanned SPS hardware elements; i.e., what elements need what propulsion systems.

- Define propulsion requirements which allow comparison of high and low thrust systems for orbit to orbit transfer.

- Define vehicle and system element inventory required for orbit to orbit transfer.

- Develop backup and redundancy requirements

- Determine the mission plan for ground and flight operation, including preliminary timelines and equipment, facility inventory.

- Define natural and induced flight environments.

- Develop ground and flight operation outline and total equipment inventory and detailed timelines.

o Provide system requirements documents for the OTV's.

8. Backup - OTV Definition

Objectives

o Define backup Orbital Transfer Vehicle configuration, program plan and costs, utilizing assured technology and minimum schedule/cost uncertainties.

o Establish in detail program cost data for the recommended, backup OTV.

o Identify and assess the impact of critical design and programmatic factors.

Tasks

o Develop candidate low thrust and high thrust designs to demonstrate compatibility with performance and program requirements, and to establish relative sutiability to perform the required functions. This is accomplished in close correlation with, and partially as part of, the parametric design activity of the primary OTV.

o Select the backup OTV vehicle design and carry the design to the detailed subsystem and component level. This effort includes complete and detailed optimization for minimum costs within the defined OTV and program requirements and consists of a detailed functional analysis and definition of major hardware, software, and program elements.

o Integrate flight and GSE propulsion system elements with each other and with their appropriate SPS or program interfacing elements. This is a detailed effort to be carried to the Interface Control Document (ICD) and System Function Document level.

o Identify and assess critical technical and programmatic problem areas requiring early resolution. This effort includes analytical or laboratory feasibility demonstration of the primary OTV design and detailed support of the critical problem area assessments.

o Develop a program plan for implementation of all phases and facets of the backup OTV program.

10. Manned OTV Configuration Definition

Objectives

o Define manned OTV configurations to support manned activities related to the construction and maintenance of satellite power stations.

Tasks

o Define mission scenarios/modes and related manned OTV concepts involved in support of manned activity in the construction and maintenance of satellite power stations. The OTV concepts will be defined in terms of crew module, propulsive elements, and support systems and synthesized into total manned OTV designs.

o Select primary and backup manned OTV configurations pertaining to particular mission scenarios/modes.

o Provide systems definition for configurations. This includes general arrangement layouts, equipment lists, weight statements, and performance definition.

o Define the nonflight elements of the manned OTV configurations including facility, GSE, software, simulation, recovery systems, etc. Define requirements imposed upon other elements of the STS, including vehicles, space facilities, etc. by the manned OTV configurations.

o Derive preliminary program plans and costs estimates for the manned OTV configurations.

IX. PROGRAM DEVELOPMENT PLAN

Harold E. Benson
Systems Evaluation Off.

C. RELATED ACTIVITIES

Two studies have been conducted outside specific SPS concept evaluation studies which provide material pertinent to the SPS. One study was the "Space Station Systems Analysis Study" and the other was an "Orbital Construction Demonstration Study." These studies are particularly applicable to space projects which might be conducted during a technology advancement phase of an SPS program. They deal primarily with the construction in space of SPS test articles and the development of techniques and technologies involved in such space construction activities.

Space Station Systems Analysis Study: This study was conducted in parallel with the release of two contracts; one with the McDonnell Douglas Astronautics Company, managed by the Johnson Space Center (contract #NAS9-14958) and the other, the Grumman Aerospace Corporation, managed by the Marshall Space Flight Center (contract #NAS8-31993). These studies were completed in June 1977. Their objective was to develop cost effective options for orderly developmental growth from shuttle sortie flight to a permanently manned space facility. Such a facility would perform construction of sub-scale SPS test articles which would test and verify construction, performance and operational aspects of an SPS program. In addition, it would be capable of assemblying large communications and radiametry antennas to serve a variety of earth needs. It would provide a platform for conducting investigations of space processing as well as other applications and pure science activities.

Orbital Construction Demonstration Study: This study, conducted by the Grumman Aerospace Corporation under contract NAS9-14916, provided a baseline concept for developing and verifying space construction technologies. The major emphasis of this study was to build a platform or factory floor in space tended by the Shuttle. Such a platform could enhance the Shuttle capability by providing a large platform for mounting construction experiments and large quantities of power for running experiments and increasing Shuttle orbit stay times.

X. PROGRAM COST

Richard C. Wadle
Systems Evaluation Off.

A. COST SENSITIVITY STUDIES

Parametric studies have been performed using the COPS (Costing of Power from Satellites) computer program. Unless otherwise indicated, the implementation scenario used for analysis is Scenario B of JSC Report No. 11568, page III-3. The satellite is the truss configuration for geosynchronous orbit assembly.

1. Sensitivity Analysis

Cost and mass parameters of transportation, satellite, assembly and ground systems were individually reduced by 50 percent from the baseline values. The impact of these reductions on cost of power was assessed and a priority ranking of the top 25 parameters was developed as shown in Figure X-A-1. The definition of each parameter is shown in Table X-A-1 along with the baseline value. The most significant parameter was HLLV per flight cost with solar blanket mass a close second. The priority ranking of Figure X-A-1 gives an indication of the parameters upon which to concentrate to achieve significant cost reductions. Solar blanket mass and solar blanket cost are included in the top 5 parameters, therefore, a closer examination has merit.

2. Solar Cell Mass, Cost and Efficiency

In order to assess the impact of solar cell parameters on the cost of power, the effect of reducing solar cell mass, cost and efficiency was evaluated. The analysis was performed for a concentration ratio of two. A nominal solar cell cost of $72/m^2 (approximately $300/Kw at 10.3 percent efficiency) was assumed with a minimum cost of $5/m^2. The solar cell efficiency was varied from 5 to 20 percent. At 10 percent solar cell efficiency and baseline mass, the cost of power can be reduced by 9 mills/kwh from the baseline by using the $5/m^2 cell cost. As a point of comparison, a gallium arsenide cell with concentration ratio of one and 17.5 percent efficiency results in a cost of 54.5 mills/kwh compared to 60 mills/kwh for a 10 percent efficient silicon cell with baseline mass. Figure X-A-2 displays the above results and also indicates that reduction of solar cell mass by incremental amounts significantly reduces the cost of power. Data for silicon solar cells with concentration ratio of one is shown in Figure X-A-3. The cost of power increases from 60 mills/kwh to 79 mills/kwh when concentration ratio is changed from two to one for a 10 percent efficient cell with the baseline mass.

3. Satellite Implementation Rate

To assess the impact of implementation rate on cost of power, a scenario with a constant implementation rate of four satellites per year was examined. For this case, the cost of power was 54 mills/kwh as compared

Figure X-A-1

SPS SENSITIVITY ANALYSIS

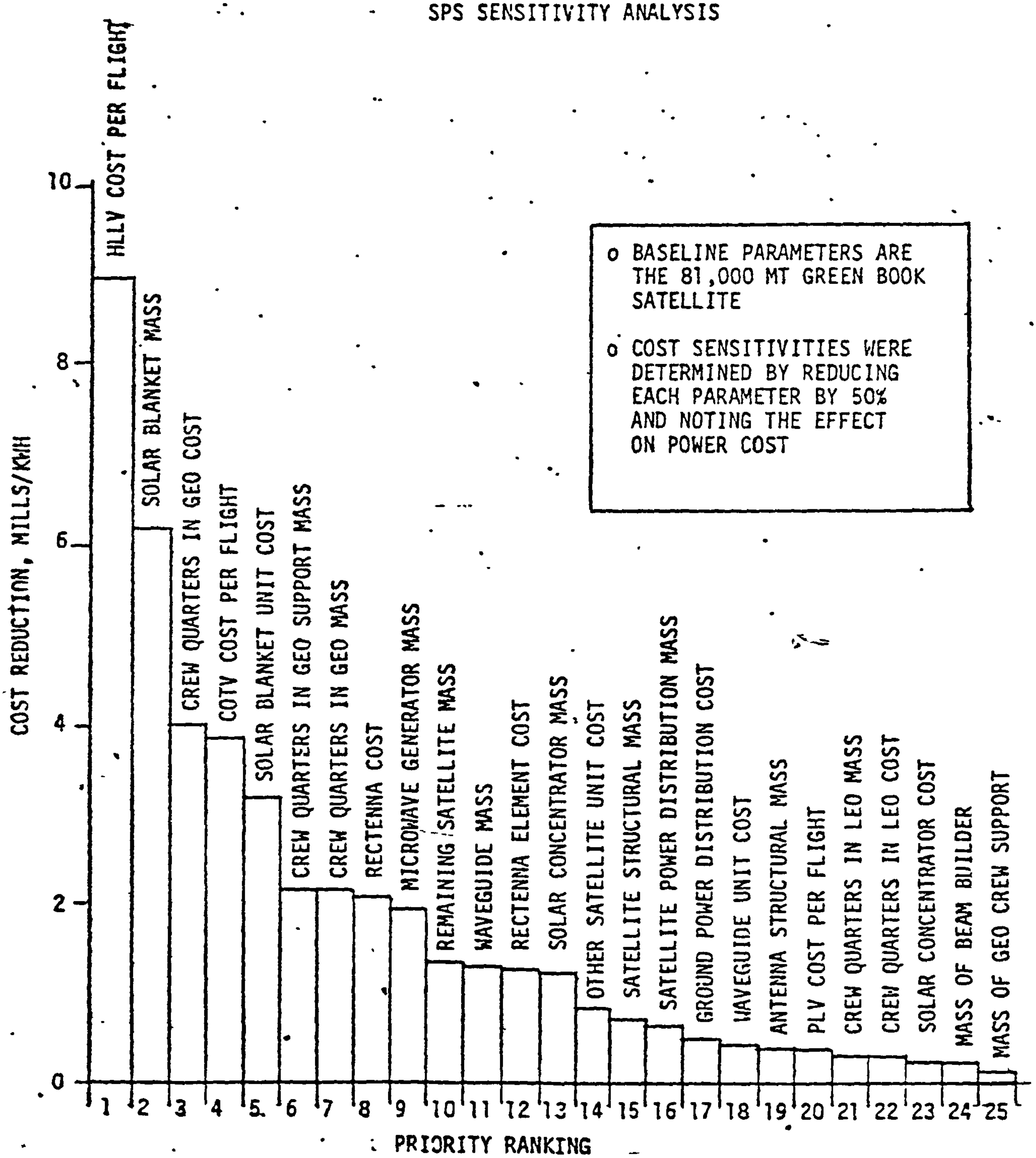


Table X-A-1

DEFINITION OF SPS COST SENSITIVITY PARAMETERS

PARAMETER	NOMINAL VALUE
HLLV PER FLIGHT COST ($/FLIGHT)	23×10^6
SOLAR CELL MASS (MT)	28,677
CREW QUARTERS IN GEO COST ($/MT) (SPACE STATION AND SUPPORT)	2×10^6
COTV PER FLIGHT COST ($/FLIGHT)	10×10^6
SOLAR CELL UNIT COST ($/M^2)	72
CREW QUARTERS IN GEO SUPPORT MASS (MT/SPS) (SPACE STATION EQUIPMENT PER SPS)	1,000
CREW QUARTERS IN GEO MASS (MT/SPS UNDER CONSTRUCTION) (SPACE STATION)	6,000
RECTENNA STRUCTURE COST ($/M^2)	10
MICROWAVE GENERATOR MASS (MT)	8,846
REMAINING SATELLITE MASS (ANTENNA DISTRIBUTION MASS, PHASE CONTROL MASS, POINTING MASS, OTHER MASS)	1,698
WAVEGUIDE MASS (MT)	4,002
RECTENNA ELEMENT COST ($/M^2)	190
SOLAR CONCENTRATOR MASS (MT)	5,735
OTHER SATELLITE COST ($/MT)	1×10^6
SATELLITE STRUCTURAL MASS (MT)	2,973
SATELLITE POWER DISTRIBUTION MASS (MT)	3,000
GROUND POWER DISTRIBUTION COST ($/M^2)	2.50
WAVEGUIDE COST ($/MT)	70,000
ANTENNA STRUCTURE COST ($/MT)	70,000
PLV PER FLIGHT COST ($/FLIGHT)	10×10^6

Table X-A-1 (cont'd)

PARAMETER	NOMINAL VALUE
CREW QUARTERS IN LEO MASS (MT/SPS UNDER CONSTRUCTION)	1,000
CREW QUARTERS IN LEO COST ($/MT)	2×10^6
SOLAR CONCENTRATOR COST ($/M^2)	.70
MASS OF BEAM BUILDERS (MT/Machine)	14.5
MASS OF GEO CREW SUPPORT (MT/PERSON/YEAR)	2.5

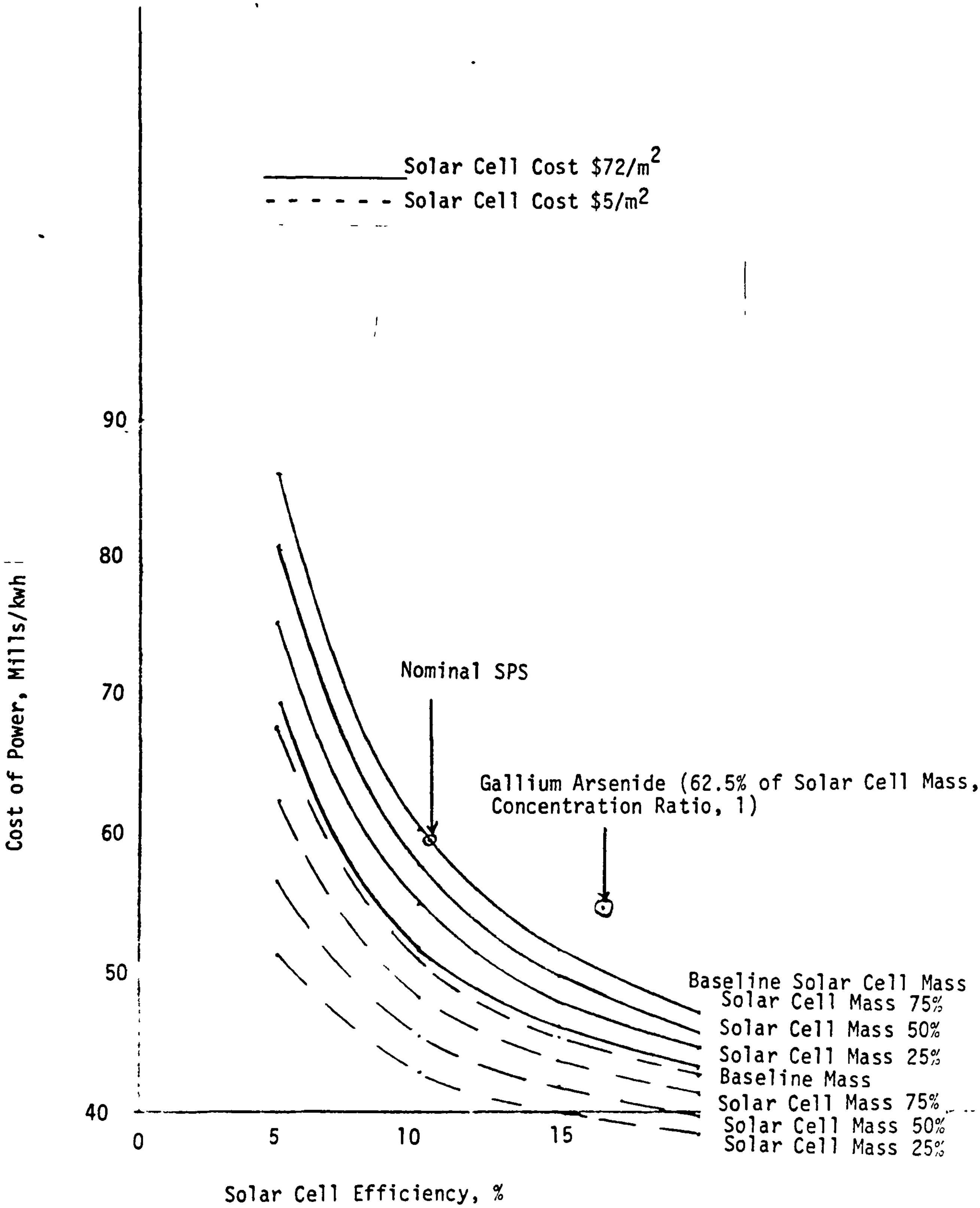


Figure X-A-2 - Effect of Solar Cell Mass and Efficiency on Cost of Power (Concentration Ratio 2)

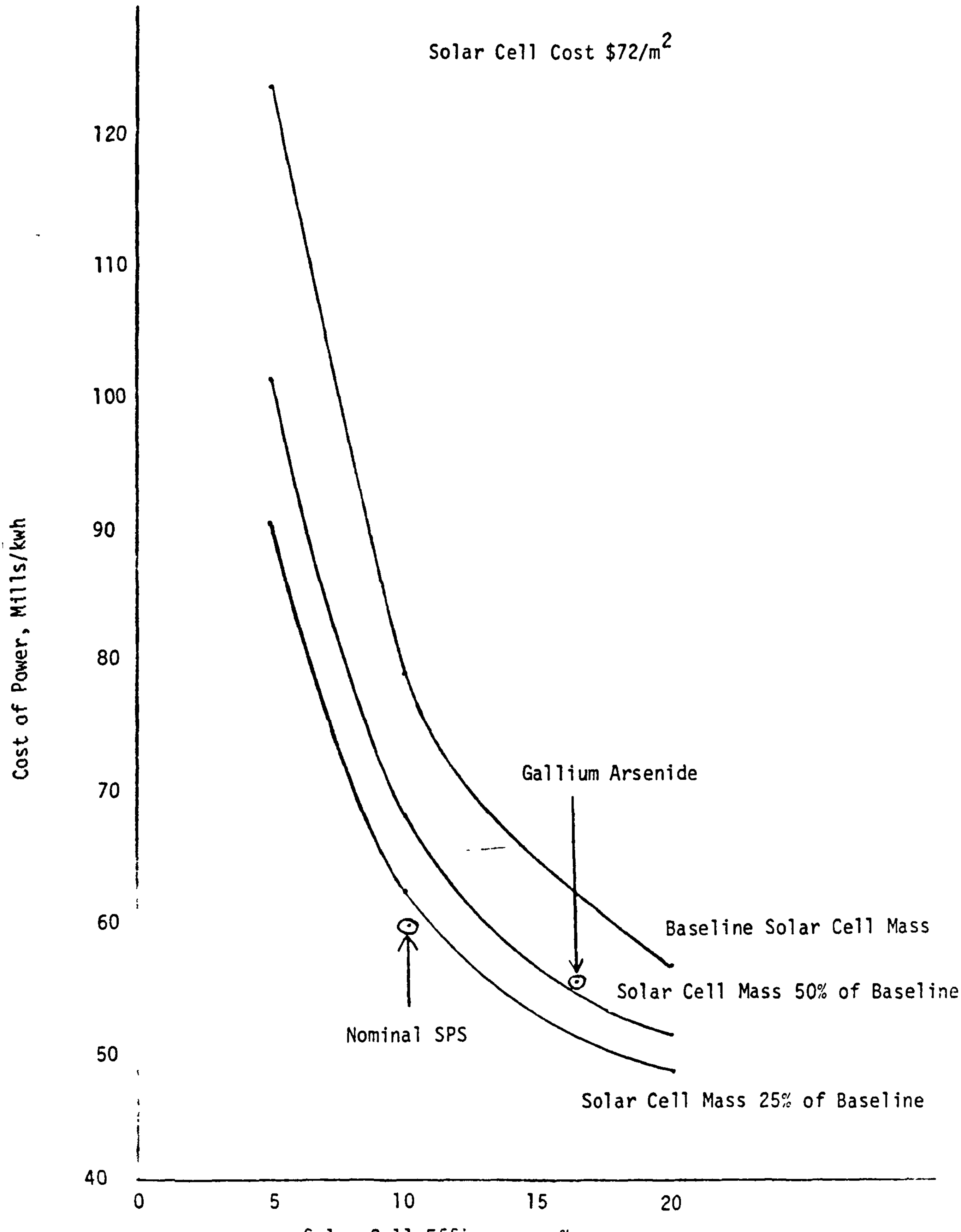


Figure X-A-3 - Effect of Solar Cell Mass and Efficiency on Cost of Power (Concentration Ratio 1)

to 59 mills/kwh for the Scenario B. The cost savings results from fewer space stations required and fewer assembly machines, as shown in Table X-A-2.

4. DDT&E

In JSC Report No. 11568, the DDT&E cost in mills/kwh was computed based on an average number of satellites operational over the 30 year period. This amounts to approximately one mill/kwh. No interest was charged for the use of the money over the time it was being used. The Scenario B implementation was evaluated using a $50 billion DDT&E evenly distributed over 10 years at 7 percent interest. The cost of power was increased by 12 mills/kwh using the above figures. To parametrically evaluate the effect of DDT&E on cost of power, a set of computer runs was made using the following satellite implementation rates - one satellite per year, two per year for 28 years. The DDT&E was assumed to be zero, 25 billion, 50 billion and 75 billion dollars over a 10 year period, at zero interest and 7 percent interest. The results of the study are shown in Figure X-A-4. The effect of DDT&E on cost of power is approximately 2 mills per 25 billion DDT&E with a four satellite per year implementation rate. If the DDT&E is 75 billion dollars at 7 percent interest for 10 years, the cost of power is 81 mills/kwh for 28 satellites, but only 60 mills per kwh for 112 satellites. The interest rate is also a significant factor since for an interest rate of zero on DDT&E, the cost of power becomes 75 mills/kwh and 58 mills/kwh for the above case. If DDT&E can be ignored, then the cost of power is 53.5 mills/kwh for the three constant implementation scenarios chosen.

5. SPS Cash Flow

The cost of power is a function of the required rate of return on the investment. The average rate of return used by utility companies is 15 percent. The significant reduction in cost of power which can be achieved by reducing rate of return is shown in Figure X-A-5. The Scenario B baseline cost of power is 59 mills/kwh for 15 percent rate of return, but drops to 42 mills/kwh for a 7 percent rate of return. Figure X-A-6 shows the breakdown of the 15 percent rate of return used by private utility companies. For this rate of return, a cash flow is shown for the baseline case.

EFFECT OF SCENARIO ON COST OF POWER
(112 SATELLITES OPERATING)

4 SATELLITES/YEAR 50 YEARS OPERATION	SCENARIO B 50 YEARS OPERATION	4 SATELLITES/YEAR 31 YEARS OPERATION	SCENARIO B 31 YEARS OPERATION
51 MILLS/KWH	52 MILLS/KWH	54 MILLS/KWH	59 MILLS/KWH

Table X-A-2

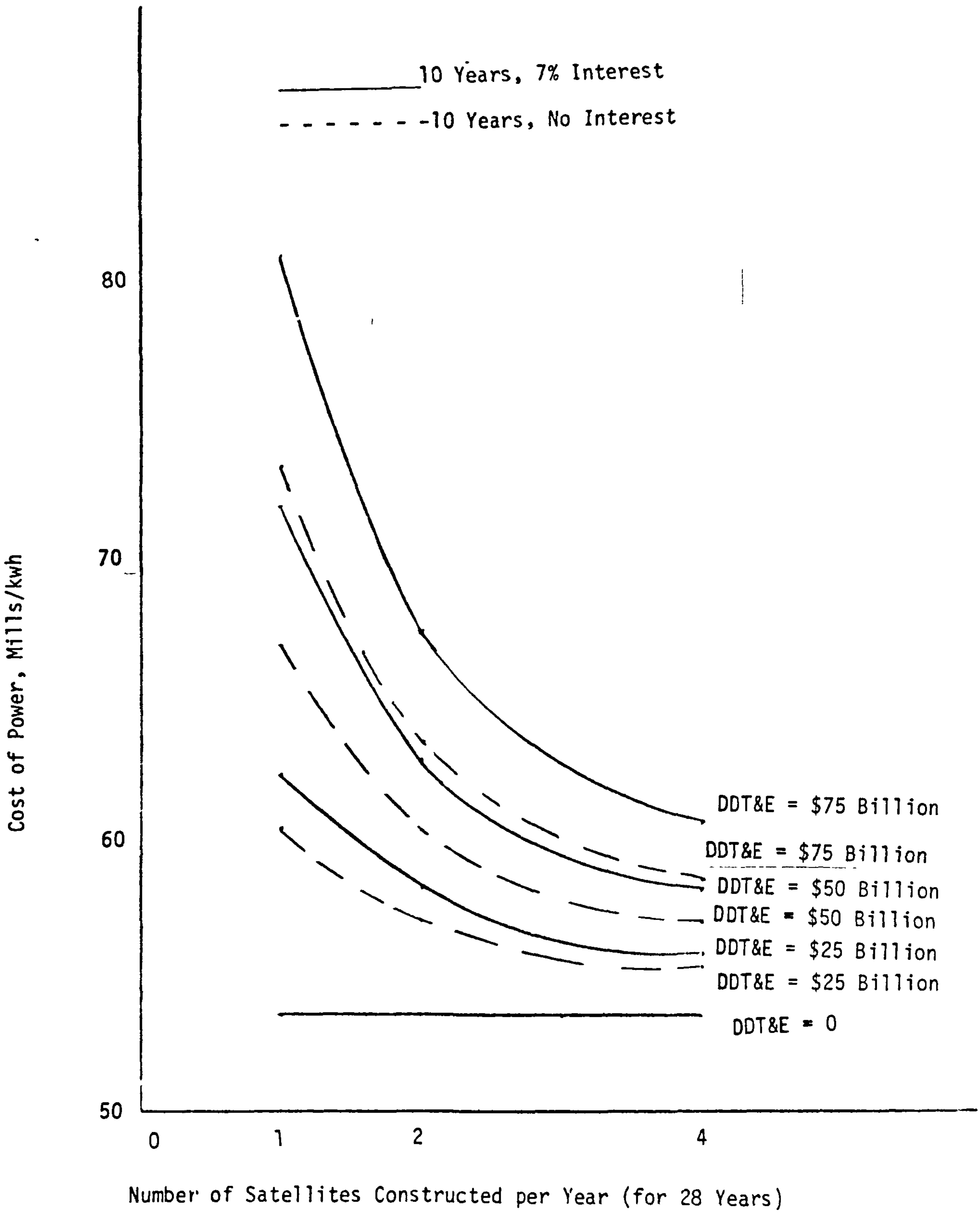


Figure X-A-4 - Effect of DDT&E on Cost of Power

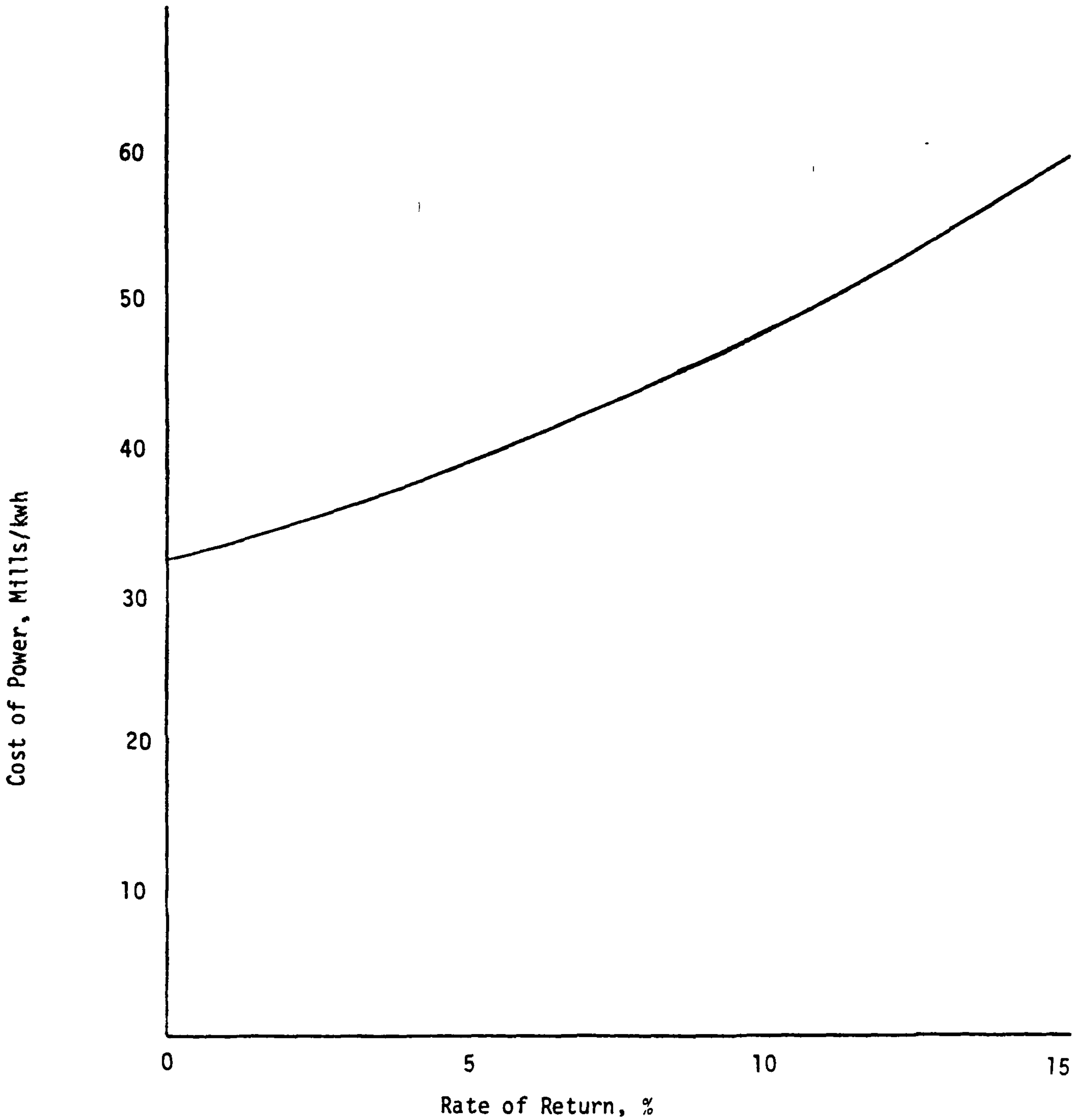
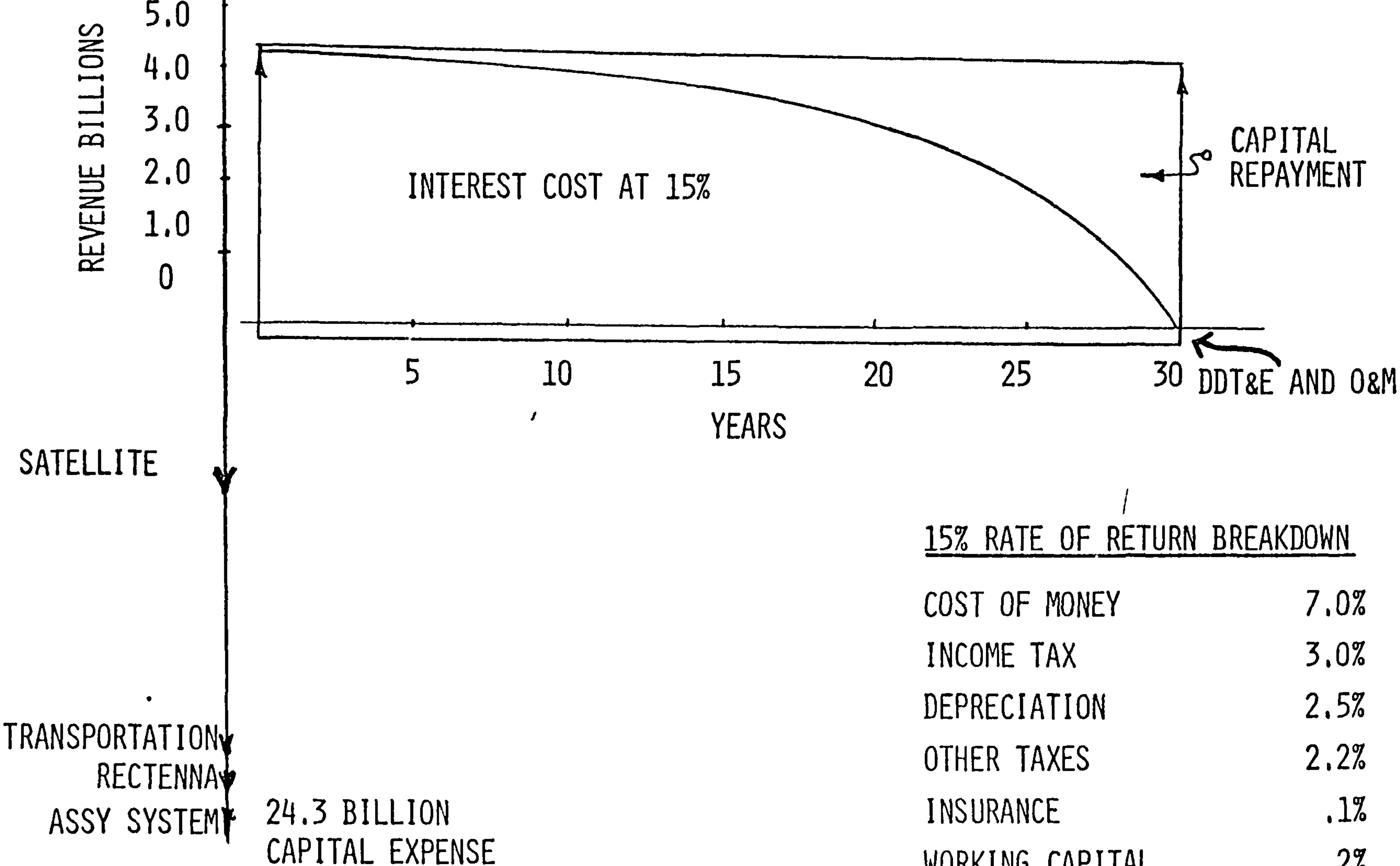


Figure X-A-5 - Effect of Rate of Return on Cost of Power

Figure X-A-6

SPS CASH FLOW

59 MILLS/KWH REVENUE = 4.755 BILLION PER YEAR = 142.7 BILLION IN 30 YEARS



15% RATE OF RETURN BREAKDOWN

COST OF MONEY	7.0%
INCOME TAX	3.0%
DEPRECIATION	2.5%
OTHER TAXES	2.2%
INSURANCE	.1%
WORKING CAPITAL	.2%

X-B. METHODOLOGY DOCUMENTATION

Richard C. Wadle
Systems Evaluation Off.

A computer model COPS (Cost of Power from Satellites) has been developed to rapidly assess changes in SPS in terms of ultimate power cost. Identification of major cost drivers can be made and ultimate cost can be minimized by optimizing design and installation rate.

The SPS costs are broken down into cost of four subsystems: satellite, assembly, ground systems and transportation. These capital costs are computed by the computer program and then utilized in a cost subroutine which utilizes a present value technique. The approach forces total cost and total income for n years to be equal by iterating on cost of power (mills/kwh). The convergence is to within .01 mills/kwh.

To arrive at an answer for a given case, it is necessary to provide the computer program with input data for each subsystem plus data for the cost subroutine. Five namelist input arrays are utilized:

a. INPUT (Primarily transportation and scenario parameters)

b. SATEL (Satellite parameters, masses, costs, etc.)

c. GROUND (Ground system-rectenna-parameters)

d ASSEM (Assembly system parameters)

e. FINAN (Financial parameters such as taxes, interest, inflation, etc.)

The input data used in the baseline case is shown in Table X-B-1. The output resulting from the computer program utilizing this data is presented in Appendix X-A. As an aid to a potential use of the program, Figure X-B-1 shows the order of input to the program. The logic diagram for the program is shown in Figure X-B-2. Appendix X-B is the computer program listing.

The logic diagram for the program is shown in Figure X-B-2. The program is divided into satellite, assembly, ground and transportation systems and a financial subroutine. From the flow diagram one can see that the satellite and assembly system outputs are used as input to the transportation calculations Also the cost of each system is computed and utilized by the financial subroutine to compute the cost of the power in mills/kwh. Table X-B-1 is a detailed list of input parameters for each section of the program along with the nominal numerical value for each. If the design should change, any or all of these parameters can be altered as necessary.

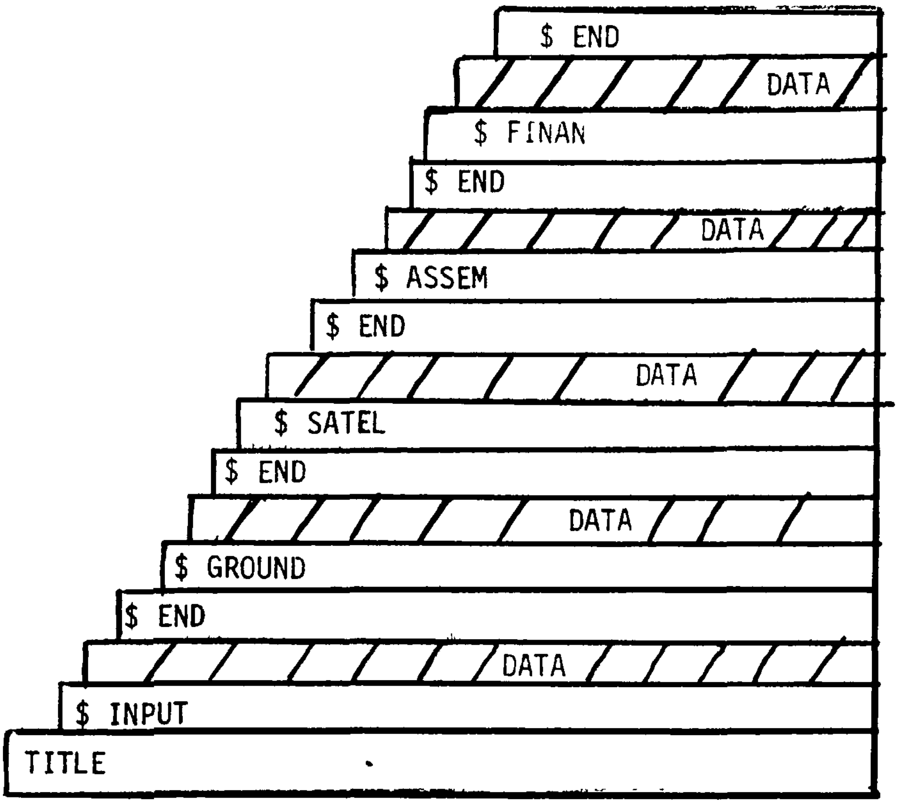


FIGURE X-B-1 - INPUT SETUP

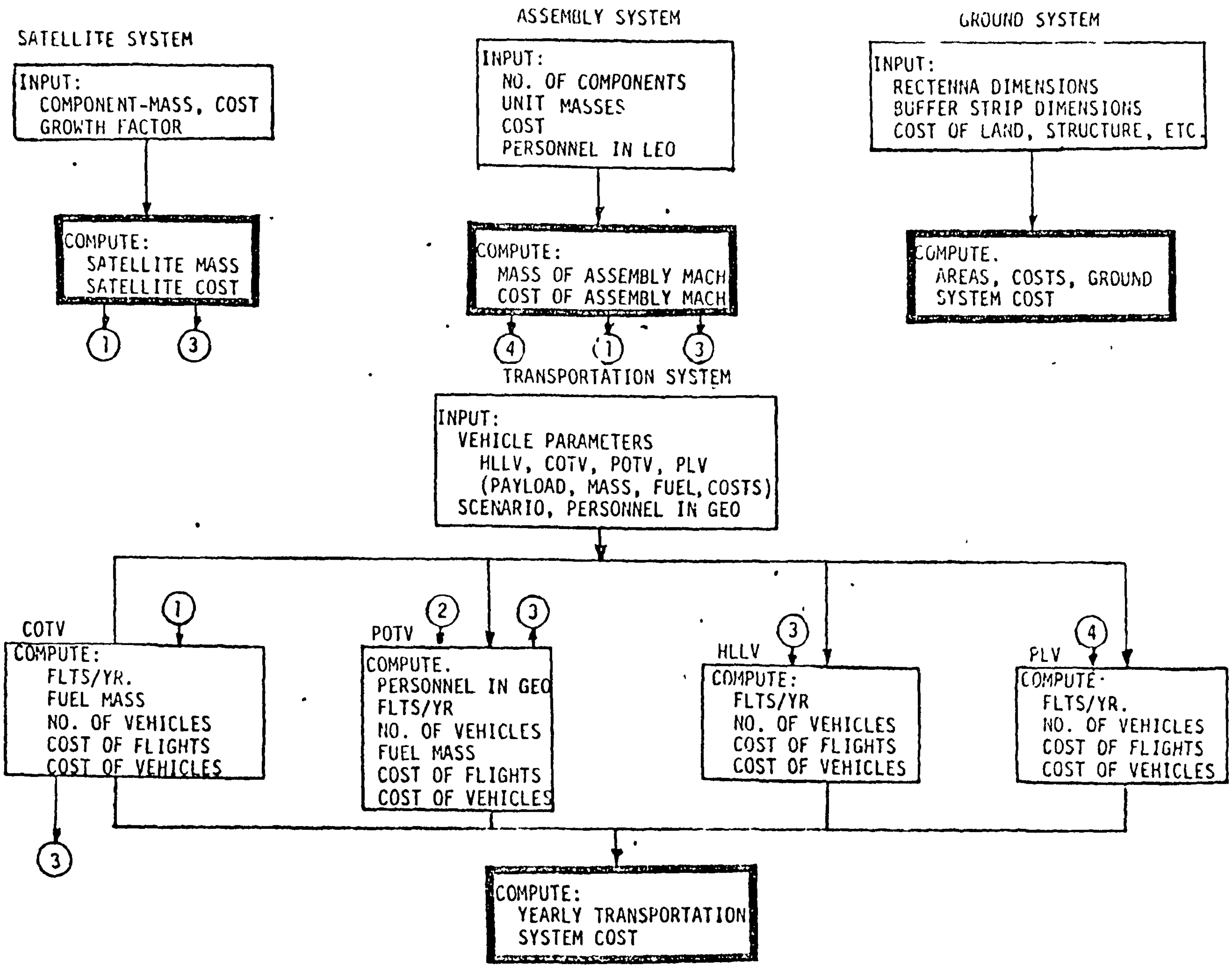


FIGURE X-B-2 LOGIC DIAGRAM

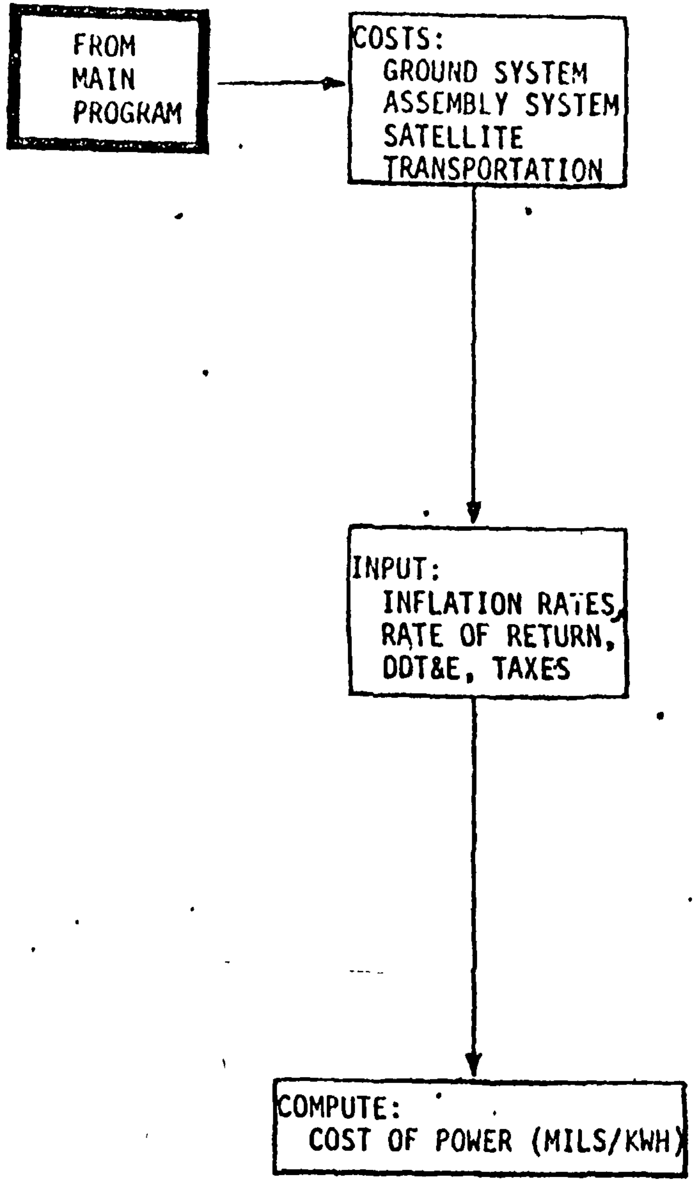


FIGURE X-B-2 (cont'd) FINANCIAL SUBROUTINE

TABLE X-B-1

<u>Input</u> (Transportation and Scenario Array)

VARIABLE DESCRIPTION	VARIABLE NAME	NOMINAL VALUE	INPUT VALUE
COTV VEHICLE MASS	COMASS	35MT	
COTV PAYLOAD	FLTMASS	250MT	
COTV LIFE TIME	CLIFE	30 FLTS	
POTV FUEL MASS/FLT	FUELPT	475MT	
POTV VEHICLE MASS	PTMASS	35MT	
POTV PAYLOAD	POTVP	230 PERSONS	
POTV LIFE TIME	TLIFE	30 FLTS	
CREW ROTATIONS/YEAR	ROTYR	4	
HLLV PAYLOAD	HLVPL	700MT	
HLLV TURNAROUND TIME	TURNRD	6 DAYS	
HLLV LIFE TIME	HLIF	300 FLTS	
HLLV AVAILABILITY	AVAIL	0.8	
SPS O&M RATE	OMRAT	0	
COTV COST/FLIGHT	CCOTVF	$\$10X10^6$/FLT	
HLLV COST/FLIGHT	CHLLVF	$\$23X10^6$/FLT	
COTV COST/FLIGHT	CPOTVF	$\$15X10^6$/FLT	
PLV COST/FLIGHT	CPLVF	$\$10X10^6$/FLT	
COTV VEHICLE COST	CCOTV	$0/EA	
HLLV VEHICLE COST	CHLLV	$0/EA	
POTV VEHICLE COST	CPOTV	$0/EA	
PLV VEHICLE COST	CPLV	$0/EA	
PLV PAYLOAD	PLVP	50 PERSONS	
PLV TURNAROUND TIME	PLVTR	11 DAYS	
PLV LIFE TIME	VLIFE	100 FLTS	
LENGTH OF SCENARIO	NYR	31	
FIRST YEAR OF SCENARIO	IYR	1996	
SPS BUILT IN YEAR I	SPSYR	VECTOR	
COTV FUEL MASS/FLT	FUELCO	475MT	
PERSONNEL IN GEO PER SPS	PFLT	389	
POWER DELIVERED AT GROUND KW	POWG	$10x10^6$	

TABLE X-B-1

<u>Ground</u> (Ground System Input Array)

VARIABLE DESCRIPTION	VARIABLE NAME	NOMINAL VALUE	INPUT VALUE
RECTENNA MAJOR AXIS	A	10KM	
RECTENNA MINOR AXIS	B	13KM	
BUFFER ZONE WIDTH	S	0.1KM	
UNIT LAND COST	LAND	$ 15/M^2	
UNIT SITE PREP COST	PREP	$.40/$M^2$	
POWER MANAGEMENT COST	PWR	$2.50/$M^2$	
SUPPORT STRUCTURE COST	GMATER	$10.00/$M^2$	
BUFFER ZONE UNIT COST	ZONE	$0.15/$M^2$	
NUMBER OF ELEMENTS	ELEMT	190./M^2	
COST PER ELEMENT	CELEMT	$.03/ELEMENT	

TABLE X-B-1

SATEL (Satellite System Input Array)

VARIABLE DESCRIPTION	VARIABLE NAME	NOMINAL VALUE	INPUT VALUE
SOLAR CELL MASS	SCELLM	24,793 MT	
CONCENTRATOR MASS	CONCM	4,958 MT	
STRUCTURE MASS	STRUCM	2,851 MT	
POWER DIST'N MASS	PDISTM	2,883 MT	
MICROWAVE GENERATOR MASS	GENRM	8,846MT	
WAVEGUIDE MASS	WAGDM	4,002MT	
ANTENNA STRUCTURE MASS	ASTRUM	1,210MT	
ANTENNA DIST'N MASS	ADISTM	167MT	
ROTARY JOINT MASS	RJOINM	635MT	
PHASE CONTROL MASS	PCONM	358MT	
POINTING CONTROL MASS	POINTM	1MT	
OTHER MASS	OTHERM	537MT	
GROWTH FACTOR	GROWF	1.5	
SOLAR CELL CER	SCELLC	$4.46 X 10^9$	
CONCENTRATOR CER	CONCC	$ .868 X 10^8	
STRUCTURE CER	STRUCC	$7,000/MT	
POWER DIST'N CER	PDISTC	$4,000/MT	
MICROWAVE GEN CER	GENRC	$2,000/EA	
WAVEGUIDE CER	WAGDC	$70,000/MT	
ANTENNA STRUCTURE CER	ASTRUC	$70,000/MT	
ANTENNA DIST'N CER	ADISTC	$40,000/MT	
ROTARY JOINT CER	RJONC	$100,00C/MT	
PHASE CONTROL CER	PCONC	$56EA	
POINTING CONTROL CER	POINTC	$1.5X$10^6$/MT	
OTHER MASS CER	OTHERC	$1.X$10^6$/MT	
NO. OF MICROWAVE & PHASE CON UNITS	UNITN	340,000	
UNIT SOLAR CELL MASS	USCELM	.4 KG/M^2	
UNIT CONCENTRATOR MASS	UCONCM	.04 KG/M^2	
UNIT POWER DISTR MASS	UPDISM	.023256 KG/M^2	
UNIT STRUCTURE MASS	USTRUM	.023 KG/M^2	

TABLE X-B-1

SATEL (Cont'd)

VARIABLE DESCRIPTION	VARIABLE NAME	NOMINAL VALUE	INPUT VALUE
PHOTOVOLTAIC CONVERSION EFFICIENCY	NI	.103	
POWER DISTRIBUTION EFFICIENCY	N2	92	
ANTENNA POWER DISTRIBUTION EFFICIENCY	N3	.98	
DC-RF CONVERSION EFFICIENCY	N4	.87	
WAVEGUIDE EFFICIENCY	N5	.98	
ALIGNMENT EFFICIENCY	N6	.98	
ATMOSPHERIC EFFICIENCY	N7	.98	
COLLECTION EFFICIENCY	N8	.88	
RF-DC EFFICIENCY	N9	.90	
INTERFACE EFFICIENCY	N10	.99	
FLAG TO USE OR NOT USE UNIT MASSES AND EFFICIENCIES	FFF	=0 - USE EFF ≠ - DO NOT USE EFF	
SOLAR CELL COST $\$/m^2$	CELC	71.98	
CONCENTRATOR COST$\$/m^2$	CCONC	.70	
CONCENTRATION RATIO	CRATIO	2.	
CONCENTRATION RATIO FACTOR	FACTO	2.	

TABLE X-B-1

<u>ASSEM</u> (Assembly System Input Array)

VARIABLE DESCRIPTION	VARIABLE NAME	NOMINAL VALUE	INPUT VALUE
NUMBER OF BEAM BUILDERS	BBMN	56/AM	
NUMBER OF CABLE RIGGERS	CRMN	20/AM	
NUMBER OF CELL INSTALLERS	CELINN	4/AM	
NUMBER OF REFLECTOR INSTALLERS	REFLIN	4/AM	
DIST'N INSTALLERS	DHIN	8/AM	
MANNED MANIPULATORS	AMMN	8/AM	
FACILITY MANIPULATORS	FAMN	12/AM	
SUBARRAY INSTALLERS	SUBINN	4/AM	
GEO CREW QUARTERS MASS	CRQTG	1,000MT	
LEO CREW QUARTERS MASS	CRQTL	1,000MT	
GEO SUPPORT MASS PER PERSON	PRQTS	2.5MT/P/YR	
GEO CREW QUARTERS PER MACHINE	CQGEO	6.000MT	
BEAM BUILDER UNIT MASS	UBBM	14.5MT	
CABLE RIGGER UNIT MASS	UCRM	14.5MT	
CELL INSTALLER UNIT MASS	UCELIN	14 5MT	
REFLECTOR INSTALLER UNIT MASS	UREFLI	14.5MT	
DIST INSTALLER UNIT MASS	UDHI	14.5MT	
MANNED MANIPULATOR UNIT MASS	UAMM	14.5MT	
FACILITY MANIPULATOR UNIT MASS	UFAM	14.5MT	
SUBARRAY INSTALLER UNIT MASS	USUBIN	14.5MT	
BEAM BUILDER UNIT COST	CBBM	$\$2X10^6$/MT	
CABLE RIGGER UNIT COST	CCRM	$\$2X10^6$/MT	
CELL INSTALLER UNIT COST	CCELIN	$\$2X10^6$/MT	
REFLECTOR INSTALLER UNIT COST	CREFLI	$\$2X10^6$/MT	
DIST'N INSTALLER UNIT COST	CDHI	$\$2X10^6$/MT	
MANNED MANIPULATOR UNIT COST	CAMM	$\$2X10^6$/MT	
FACILITY MANIPULATOR UNIT COST	CFAM	$\$2X10^6$/MT	
SUBARRAY INSTALLER UNIT COST	CSUBIN	$\$2X10^6$/MT	
LEO QUARTERS UNIT COST	CLEO	$\$2X10^6$/MT	
GEO QUARTERS UNIT COST	CGEO	$\$2X10^6$/MT	
PERSONNEL IN LEO	PLEO	145	

TABLE X-B-1

FINAN (Financial Input Parameter)

VARIABLE DESCRIPTION	VARIABLE NAME	NOMINAL VALUE	INPUT VALUE
ADVALOREN TAX RATE	PTAXR	0	
GEN INFLATION RATE	GENINF	0	
OPR INFLATION RATE	OPPINF	0	
POWER INFLATION RATE	INFLP	0	
RATE OF RETURN	ROR	15%	
PLANT FACTOR	PF	92%	
O&M RATE	OMR	0	
DDT&E INTEREST RATE	INTR	8%	
DDT&E PERIOD	TIME	10 YRS	
TOTAL DDT&E	TDDTE	0	
COST OF POWER STEP SIZE	DELR	.001 CENTS/KWH	
INITIAL GAINS AT COST OF POWER	RATE	.001 CENTS/KWH	

X-C. COMPARATIVE COST ANALYSIS

Ronald Harron
Systems Evaluation Off.

Cost analysis studies of the SPS, its development and operation have been performed by several organizations over the past two years. The goal of each of these studies was to determine the unit cost of an SPS in terms of dollars per kilowatt installed capacity, and, by coupling this result with various financial and operational parameters, arrive at a power rate in terms of mills per kilowatt hour.

1. Source of Estimates

SPS cost estimates were made by these organizations:

a. ECON, Incorporated - this cost analysis was made under contract NAS8-31308 with MSFC. The Grumman Aerospace Corporation provided supportive engineering information. For the purposes of this comparative analysis, the data presented was taken from ECON First Interim Report No. 76-145-IB dated March 31, 1976; ECON Second Interim Report No. 76-145-2 dated June 30, 1976, and Grumman Aerospace Corporation Space-based "Solar Power Conversion and Delivery Systems [Study]" dated August 6, 1975.

b. MSFC - this cost and economic analysis was conducted by MSFC concurrently with their generation of technical data in support of a systems engineering study of the SPS. Data obtained for this comparative analysis was obtained from "Solar Power System - Engineering and Economic Analysis (Summary)" NASA TMX-73344 dated November 15, 1976.

c. JSC - this study was conducted by JSC as an evaluation of the SPS with the objective of establishing realistic design criteria and requirements for a full scale SPS program. Data for this analysis was obtained from "Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts" publication JSC 11568 dated August 31, 1976.

d. JSC produced a second cost estimate using the technical data of "Initial Technical Environmental and Economic Evaluation of Space Solar Power Concepts." This estimate differed in three significant ways from the initial JSC estimate; (1) The PRICE model developed by RCA was used extensively to generate component costs, (2) learning advantages due to extremely large production runs was incorporated, and (3) a more comprehensive set of assembly station design data was used.

e. JPL - this cost study was conducted by JPL in support of their evaluation of central power stations. Data for this comparative analysis was obtained from "An Initial Comparative Assessment of Orbital and Terrestrial Central Power Systems" Final Report, JPL publication No. 900-780 dated March 1977 and supporting documentation.

2. Estimates Made

The actual cost estimates produced by each of the estimators is shown in Table X-C-1. A direct comparison of capital cost is possible in all cases except the MSFC cost which was reported in terms of life cycle cost. Although the figures presented have been corrected to remove the effects of taxes and insurance on life cycle capital cost, no other corrections have been made.

The cost of power in terms of mills per kilowatt hour is probably more directly compatible. Differences here are primarily due to differences in design, operational and economic assumptions.

TABLE X-C-1

Estimate Source	CAPITAL COST ($/KW)			POWER RATE (MILLS/KWH)		
	Low	Nominal	High	Low	Nominal	High
ECON	2,440	2,840	2,980	30	50	59
MSFC	2,316	4,486	9,190	32	62	127
JSC	1,400	3,000	5,780	29	59	115
JSC*	---	2,287	---	---	38	---
JPL	4,600	5,600	7,153	40	118	485

3. Effect of Major Cost Drivers

As was pointed out in part A of this section, certain design variables such as solar cell cost and mass, certain installation costs such as transportation to geogynchronous orbit and certain unit costs such as microwave transmission systems costs per kilowatt have a profound effect on the cost of delivered electrical power. To this list of SPS parameters, operational variables such as load factor, transmission efficiencies, etc., and economic variables such as the discount rate must be added. Relatively minor variations in these variables can result in large changes in the resultant cost of power.

Table X-C-2 contains a listing of some of these major cost drivers along with the values assumed by each of the estimators. It must be emphasized that many of these values are not explicitly stated in the referenced data sources. Such values have been calculated or inferred for the sake of completeness.

4. The Range of the Estimates

Most of the estimators included a range of their estimates. This range was developed by assuming different design configurations on different weight, efficiency or unit cost data. The singular exception to this approach was JPL who obtained their high estimate by assuming that each subelement of the SPS was produced at the highest possible cost and operated at the lowest possible efficiency. This approach produced a high limit of 485 mills per kilowatt hour, four times higher than the nominal cost.

While this is one legitimate way of obtaining the upper bound, it is most unlikely that such a sequence of adversity will actually occur. The range, as stated by all other estimators is more likely to be from a low of 30 mills per kilowatt hour to a high of 120 mills per kilowatt hour.

TABLE X-C-2*

VARIABLE	ECON	MSFC**	JSC	JSC***	JPL
Xport to GEO ($/kg)	182	182	152	31.79	145
Solar Blanket ($/kW)	===	834	300	130	921
Solar Blanket ($/m²)	54	59	42	42	104
Surface Density (Kg/m²)	===	.61	.62	.62	.95
Microwave System ($/kW)	368	559	329	766	520
Solar Blanket Eff. (%)	===	13.7	10.3	10.3	8.4
Microwave System Eff. (%)	60	58	60.6	60.6	60
Overall System Eff. (%)	===	7.9	5.36	5.36	4.2
Load Factor	.95	.85	.92	.92	.864
Discount Rate (%)	7.5	7.5	15	15	15
Construction Time (years)	1	2	1	1	6

*Nominal Data
**Adjusted Life Cycle Cost
***Costs Using Price Model and Learning

X. PROGRAM COST

Resources Mgmt. Office
H. Mandell, W. Whittington,
D. Webb, W. Haldeman,
T. Foster, G. Bauch

D. SYSTEMS COST ANALYSIS

1. INTRODUCTION

1.1 Estimating Environment & Purpose

In developing cost estimates for the SPS, it should first be recognized that every element of the program is either undefined, or at best, in a preliminary state of definition.

However, despite these limitations, there are many very valid reasons for developing cost estimates; one of the main reasons is to enable better estimates to be made in future iterations. In addition, these estimates can be used quite well to identify the areas of cost sensitivity requiring further technical definition and cost analysis, and thus can serve to prioritize future analysis. While they can also be used to scope the total magnitude of the program, and are adequate to support such decisions as identification of conceptual trade studies, they should be used very guardedly, if at all, in such matters as establishing peak budget levels. It is felt, however, that early year budgets can be roughly scoped at this point in time. The final reason for performing these estimates was to identify areas where new or more precise cost estimating techniques are required.

The expertise of many highly experienced estimators has been utilized. However, these people were dealing in a new and foreign area in many cases. No estimators from the utility industry were employed, for example. But one can expect that, where these estimates deal with aerospace industry products, these estimates are very reliable, especially where today's technologies are employed.

Detailed costing ground rules and assumptions are presented in each of the succeeding sections.

1.2 Configuration, Work Breakdown Structure, and Traffic Model

The SPS configuration costed was the truss configuration (reference 1), employing nominal baseline weights. The HLLV was the EDIN EX-338-76 Propane/LOX Booster, with the SSME orbiter. The COTV was the LH_2/Thermal-Electric Arc Jet concept of reference 1. Two PLV configurations were costed: the EDIN 0505 (F-1 engines in LRB) and the EDIN 0511 (New Propane/LOX Engines in PLV); the propane/lox vehicle estimates were those included in the cost summaries. The POTV vehicle was from section VI-E of reference 1. Concepts for the construction base, construction devices, and facilities were largely designed by the estimators, with inputs from the JSC Engineering and Development Directorate and from reference 1. The rectenna design was also from reference 1.

The work breakdown structure for all elements costed is given in fig X-D-1. Twelve first tier elements were involved, and over fifty second tier elements, each of which was costed individually to a lower level of detail. Scenario B (reference 1) was assumed in the development of schedules for vehicle DDT&E and deployment.

1.3 Mode of Presentation

To aid in communicating numbers of the magnitude involved, major estimates are presented in dollars per kilowatt of SPS power. DDT&E and theoretical first unit (TFU) costs are presented for all major items; all costs are in constant FY 77 dollars.

2. COSTING METHODS EMPLOYED

Cost methods employed were largely parametric. Estimating relationships used numbered in the hundreds, and most are shown in succeeding sections. For aerospace vehicles, existing data bases are considered to be very good, particularly for items employing current technologies (e.g., structures, engines), or those using technologies with familiar evolution patterns (e.g., certain avionics elements). Where time permitted, especially for the more costly items, multiple techniques were employed, and results cross-checked with results of other studies, where available.

For certain very costly items (reception system and the SPS satellite itself), the RCA PRICE Model was employed to provide an independent set of estimates; because of the lack of precise analogies for these items, the uncertainties are probably the highest of all.

All transportation elements were costed to the subsystem level, using standard NASA aerospace methods, and estimates are considered accurate and as reliable as the confidence in the current vehicle descriptions.

Because not even conceptual designs existed for the assembly station, designs were postulated based on phase B NASA space station studies, and modules postulated for a variety of purposes (living, recreation, assembly, dispensary, etc.). Descriptions of the modules used are presented. It should be remarked that no design optimization was performed for the assembly station.

Facility costs were based on a one-site desert launch complex with downrange recovery. The launch complex itself was extrapolated from the Saturn V complex 39 at KSC.

NASA-S-77-3280

SOLAR POWER SATELLITE

1.1 SATELLITE

1.1.1 COLLECTION

- SOLAR CELLS
- CONCENTRATORS
- SUPPORT STRUCTURE
  - PRIMARY
  - SECONDARY
- POWER COLLECTION
- POWER MANAGEMENT
  - PROTECTION
  - SWITCHING
  - REGULATION
- ROTARY JOINTS
- INSTRUMENTATION

1.1.2 TRANSMISSION

1.1.2.1 - STRUCTURE
- PRIMARY
- SECONDARY

1.1.2.2 - POWER DISTRIBUTION
- CONDUCTORS
- SWITCHGEAR

1.1.2.3 - MICROWAVE CONVERSION
- 2.3.1 - GENERATORS
- 2.3.2 - WAVEGUIDES

1.1.2.4 - CONTROL SYSTEM
- POINTING
- PHASE CONTROL

1.1.2.5 - INSTRUMENTATION

1.2 TRANSPORTATION

1.2.1 HLLV

- VEHICLE
- FUEL PER FLIGHT
- LAUNCH OPERATIONS
- RECOVERY OPERATIONS
- REFURBISHMENT

1.2.2 COTV

- VEHICLE
- FUEL PER FLIGHT
- REFURBISHMENT

1.2.3 PLV

- VEHICLE
- FUEL PER FLIGHT
- LAUNCH OPERATIONS
- RECOVERY OPERATIONS

1.2.4 POTV

- VEHICLE
- FUEL PER FLIGHT
- REFURBISHMENT

1.3 FABRICATION ASSEMBLY

1.3.1 SPACE CONSTRUCTION BASE

1.3.1.1 - SPACE FACILITY

1.3.1.2 - GROUND SUPPORT

1.3.2 SOLAR COLLECTION FAB AND ASSY

- BEAM BUILDERS
- REFLECTOR INSTALLERS
- SOLAR CELL BLANKET INSTALLERS
- CONDUCTOR INSTALLERS
- MOBILE MANIPULATOR
- DOCKING MODULES

1.3.3 ANTENNA FAB & ASSEMBLY

- BEAM BUILDERS
- CONDUCTOR INSTALLER
- SUBARRAY INSTALLERS

1.3.4 FAB & ASSEMBLY SUPPORT

1.4 GROUND SYSTEMS

1.4.1 TRANSPORTATION

- LAUNCH & REFURB FACILITY
- RECOVERY FACILITY

1.4.2 RECEPTION

- LAND
- SITE PREPARATION
- STRUCTURE
- DIPOLES
- GROUND PLANE
- POWER COLLECTION
- POWER MANAGEMENT
  - INVERSION
  - SWITCHGEAR
  - REGULATION

FIGURE X-D-1

3. SUMMARY OF ESTIMATES

Results of this analysis are tabulated below in cost per kilowatt (for 112 X 10" KW) for all major program elements.

In order of cost sensitivity, the costs are:

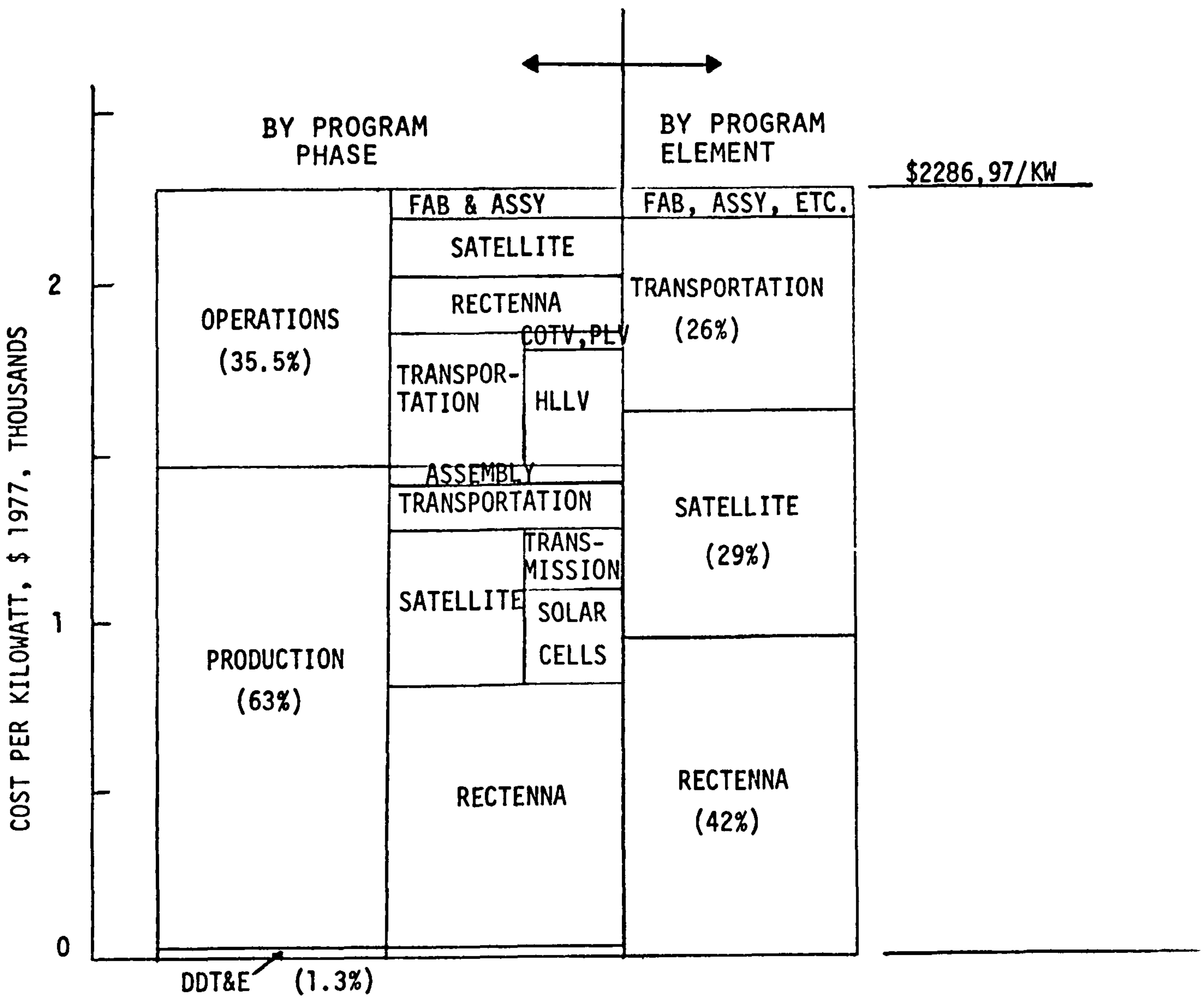
		TOTAL COSTS $/KW
1.	Ground Reception (Rectenna)	945
2.	HLLV	518
3.	Satellite Collection (Solar Collector)	397
4.	Satellite Transmission	242
5.	Construction Base	68
6.	COTV	45
7.	PLV	31
8.	Satellite Integration, Test, Maintenance	15
9.	Facilities	13
10.	All Other	13
	Total	

The relative magnitudes of the costs are portrayed on the bar chart fig. X-D-2, where the dominance of the power collection, ground reception, and transmission systems, and the HLLV operations is clearly displayed. Certain components of these costs (e.g., collector instrumentation) are very large and not fully explainable in examining the input weight data from reference 1.

A brief comparison has been made with Boeing mature industry estimates and with last year's estimates in reference 1 for the satellite system.

		Satellite Unit Cost
Reference 8	High	6173 M
	Low	2127 M
Boeing "Mature Industry"		6423 M
JSC		2287 M

SUMMARY OF ESTIMATES



FI X-D-2

6/1/77

It is encouraging that this completely independent estimate is toward the lower end of the previous range of estimates. However, it should be noted that an extremely low cost approach for the production of solar cells must be invented (i.e., a major breakthrough in production techniques will be required) for these costs to be realized.

Annual costs for the first ten years are as follows (in millions).

	DDT&E	PRODUCTION	OPERATIONS
FY 85	679		
86	1896		
87	3178		
88	5056		
89	6961		
90	7550	2174	
91	5941	3818	
92	3134	7591	14
93	1129	15098	37
94	177	8154	2310

Operations cost estimates were composed primarily of transportation costs (propellants, launch operations, vehicle maintenance and replacement) and satellite operations and maintenance (at 3% of hardware in orbit per year).

1.1 SATELLITE
(Analyst: W. F. Haldeman)

1.1.1 System

1.1.1.1 Collection

1.1.1.1.1 Solar Cells

Four approaches, as listed below were used to estimate the cost of the solar cells. These approaches were as follows:

1. RCA PRICE computer method
2. A rule of thumb
3. Boeing Mature industry approach
4. Delphi Technique

Method 1 - RCA PRICE computer method

Starting with a solar blanket and coating it by a simple manufacturing process (to be developed), a manufacturing complexity can be determined. This complexity is then adjusted downward for the general advance in technology. This along with other descriptive factors are used as inputs to the computer model. Results:

DDT&E	$183.175 M
Total Production	$190,271.728 M
Production/SAT	$1,698.9 M
Production/KW	$169.89

Method 2 - Rule of Thumb

There is a rule of thumb which says that: to accomplish the same function, the cost can be reduced to 1/3 every 10 years. In the May 1977 "Scientific American" a cost of $1.50 per watt is given. Twenty years from now it would be 1/9 or $.167 per watt or $167 per KW.

Method 3 - Boeing Mature Industry Approach

This approach is based upon the assumption that inherent within large quantity production programs in industry is a level of maturity which drives unit cost down to a level relatively close to the material cost of the item. The application of this method results in a cost in the $.10 - $.20 per watt range.

Method 4 - Delphi Technique

The Delphi technique is a formalized method of arriving at a decision based upon the opinions of experts within a stated area.

Source: Semi-Annual Review Meeting
Silicon Technology Programs
ERDA, January 1977

Motorola	$.13 per watt
Texas Instruments	.1359
GE	.17 - .20
RCA*	.20

*Directly from their Semi-Conductor people and totally independent from Method 1.

1.1.1.1.2 Concentrators

The source of information is page IV-14 of Volume I of reference 1. The nominal Truss design data was used. The assumption was that the 5735 MT (metric tons, 2200 pounds) was made up of 62 identical elements. The estimate was made for developing this element and producing 6900 of them.

DDT&E	$110.552 M
Total Production	$62,268.752 M
Production/SAT	$555.971 M
Production/KW	$55.60

1.1.1.1.3 Instrumentation

From reference 1 the undefined weight was given as 484 MT. Based on that level of information and the judgment of the estimator, the following estimates were developed:

DDT&E	$609.621 M
Total Production	$139,295.472 M
Production/SAT	$1,243,710 M
Production/KW	$124.37

1.1.1.1.4 Rotary Joints

The weight from reference 1 was 635 MT. There are two rotary joints per satellite. This is a large complex pedestal type mechanism.

DDT&E	$223.336 M
Total Production	$5,975.712 M
Production/SAT	$53.355 M
Production/KW	$5.33

1.1.1.1.5 Support Structure

From reference 1, the 2973 MT was for 150 elements. This element cost was estimated and 16800 of them were assumed to be produced.

DDT&E	$38.727 M
Total Production	$1,626.894 M
Production/SAT	$14.526 M
Production/KW	$1.45

1.1.1.1.9 Collection I&T

Based on weight and complexity of the collection items the following estimate for integration and test was developed:

DDT&E	$1,860.732 M
Total Production	$20,320.608 M
Production/SAT	$181.434 M
Production/KW	$18.14

1.1.1.2 Power Distribution

This element includes power collection, power management, and integration and test from reference. The weight used was 3000 MT. Power collection was 98% of the weight and management was 2%. Management was assumed to be more complex than the collection.

DDT&E	$141.677 M
Total Production Cost	$9,617.637 M
Production/SAT	$85.872 M
Production/KW	$8.59

1.1.2 Transmission

There are two transmission systems per satellite. Cost and weights will be kept on a per satellite basis in the following paragraphs.

1.1.2.1 Structure

According to Reference 1 the structure will weigh 1210 MT. This simple structure was split into 60 elements for costing purposes and 6720 elements were assumed to be produced.

DDT&E	$14.108 M
Total Production	$749.783 M
Production/SAT	$6.694 M
Production/KW	$.67

1.1.2.2 Power Distribution

Reference 1 indicates a weight of 167 MT; 100 MT of this was assumed to be simple material for the most part while the 67 MT for switch gear was fairly complex.

DDT&E	$37.684 M
Total Production	$1,133.279 M
Production/SAT	$10.118 M
Production/KW	$1.01

1.1.2.3.1 Microwave Conversion

Generators

From the reference 1 it was determined that 262,460 generators were required per satellite. This calls for an average monthly production rate of 81,654. The computer estimated an average cost of $2,217. Raytheon has estimated that the cost would come down to $2000 by the 1990's.

DDT&E	$3.685 M
Total Production	$65,182.000 M
Production/SAT	$581.982 M
Production/KW	$58.20

1.1.2.3.2 Wave Guides

According to reference 1, 4,002 MT of wave guides per satellite will be required. The estimate was based on standard wave guide complexity factors and the design shown.

DDT&E	$9.713 M
Total Production	$64,950.848 M
Production/SAT	$579.918 M
Production/KW	$58.00

1.1.2.3.9 Microwave Conversion I&I

Assuming a fairly complex integration and test program, the following estimates were developed:

DDT&E	$1,285.577 M
Total Production	$13,654.293 M
Production/SAT	$121.913 M
Production/KW	$12.19

1.1.2.4 Control System

1.1.2.4.1 Pointing

Reference 1 contains a weight of 1 MT for the pointing System. Based upon this weight, the following costs were estimated:

DDT&E	$0.127 M
Total Production	$260.461 M
Production/SAT	$2.326 M
Production/KW	$.23

1.1.2.4.2 Phase Control

Reference 1 indicates 358 MT of weight for this complex system. It was assumed that each of the 7854 sub-arrays weighed 100.5 and were difficult engineering items.

DDT&E	$491.863 M
Total Production	$7,951.091 M
Production/SAT	$70.992 M
Production/KW	$7.10

1.1.2.5 Instrumentation

Based upon the stated weight of 52 MT in Reference 1, the following cost estimates were developed:

DDT&E	$141.749 M
Total Production	$19,019.200 M
Production/SAT	$169.814 M
Production/KW	$16.98

1.1.2.9 Transmission I&T

The elements for which the integration and testing functions will be performed are as follows:

Structures
Power Distribution
Microwave Generator
Control System
Instrumentation

DDT&E	$878.605 M
Total	$10,835.287 M
Production/SAT	$96.744 M
Production/KW	$9.67

1.1.3 Software

This estimate of the cost of the software associated with instrumentation is based upon a historical relationship of software to hardware.

DDT&E	$2,107.610 M

1.1.4 Total Satellite I&T

This is the cost of integrating and testing the following:

Collection
Transmission
Software

DDT&E	$1,454.146 M
Total Production	$14,884.392 M
Production/SAT	$132.896 M
Production/KW	$13.29

Since the collection system represents such a large portion of the SPS, a decision was made to conduct alternate costing exercises whenever possible within the constraints of time under which the estimators were operating. The resulting numbers were not included within the total cost summaries within this document. Alternate estimates for the elements listed below are contained on the following pages:

1.1.1.2 Concentrators
1.1.1.3 Support Structures
1.1.1.6 Rotary Joints
1.1.2 Transmission System

1.1 SATELLITE - Alternate Cost Estimates

Analyst: Garland Bauch

1.1.1 Collection System

The SPS Collection System estimate is based on the Truss Configuration weights and characteristics shown in Reference 1. Table X-D-I shows the summary cost estimates for the concentrators, support structure, and rotary joints.

General ground rules are as follows:

+ One (1) flight test and .5 ground test units in DDT&E.
+ The flight test unit may be refurbished for operations.
+ See HLLV for other ground rules.

Detailed assumptions and methodology for each major subsystem are as follows:

+ Concentrators: Estimated by "grass roots" method.
  - Design Engineering: Assumed 100 MYRS for 4 yrs. at $40,000/MYR.
  - Manufacturing: Concentrator Sheet Installation for one (1) year (one SPS) based on 49 MYR from Section V. C. Construction Operation in Reference 1. Used $100,000 per MYR. (Includes hazard pay.)
  - Material: Used Kapton at $33/KG (A. D. Little) times 5,735,000 KG per SPS. The Kapton cost will decrease as production increases. Only 300,000 KG Kapton was produced in 1976. Source: JSC Engineering and Development Directorate.
+ Support Structure: Estimated by "grass roots" method.
  - Design Engineering: Assumed 500 MYRS. for 4 yrs. at $40,000/ MYR. (with direct overhead)
  - Manufacturing (unit cost): Used manpower for crews shown in Reference 1, section V. C. Construction Operations. Beam Building, Mobile Manipulator, and Facility Manipulator crews were 16.3, 6, and 15 MYRS., respectively. Used $100,000/MYR rate. MYRS for manipulator crews were split between Collection and Transmission System.
  - Material: Unit cost - Used aluminum at $2/KG by $2.27 $\overline{M}$ KG per SPS. Assumed sheet roll raw stock was taken to orbit for fabrication.
+ Rotary Joints: Used Shuttle 040C Docking System estimate and Aerospace STS Body/Tank CER exponents to derive new CER. Assumed 1.2 complexity for design and manufacturing problems due to close tolerances and arcing. Weight = 144,318 LB/joint. Two (2) joints/ SPS.

TABLE X-D-1 SPS SATELLITE COST SUMMARY
($\overline{M}$ OF 1977 DOLLARS)

		DDT&E	TFU
1.1.1	COLLECTION SYSTEM		
1.1.1.2	CONCENTRATORS	309	194
1.1.1.3	SUPPORT STRUCTURE	102	8
1.1.1.6	ROTARY JOINTS	162	68

1.1.2 Transmission System: Estimated by "grass roots" method.

Table X-D-2 shows the cost estimate for structure. Same ground rules as Collection System. (Test units - 1.5.)

+ Structure
  - Design Engineering: Assumed 200 MYRS. for 4 yrs. at $40,000/MYR.
  - Manufacturing: (unit cost) Used 12 MYRS./YR. for Antenna Primary and Support Structure Crews and Harness and Array Installation Crew (total - 36 MYRS.) Source: Section V. C. Construction Operations, Reference 1. Used $100,000/MYR.
  - Materials (unit cost): Used 1,210,000 KG aluminum at $2/KG (raw stock)
  - Tooling: Included in 1.3 Assembly.

TABLE X-D-2. SPS SATELLITE COST SUMMARY
($\overline{M}$ OF 1977 DOLLARS)

		DDT&E	TFU
1.1.2	TRANSMISSION SYSTEM		
1.1.2.1	STRUCTURE	45	6

HLLV Cost Estimate

(Garland Bauch, LS/Schedules Integration Office)

1.2.1.1 Vehicle

The HLLV estimate is based on the EDIN EX-338-76 configuration (Propane/LOX Booster). Table X-D-3 shows the summary cost estimate. The orbiter estimate is shown in Table X-D-4.

General ground rules are as follows:

- o Costs are in constant 1977 dollars
- o Inflation rate is 6%
- o No contractor fees included
- o Facilities cost (C of F) not included. See WBS 1.4.1
- o Three (3) test units are included in DDT&E
- o No learning for test units
- o Two (2) flight test units will be refurbished and used during operations
- o All estimates are derived from weight statements/technical characteristics, and JSC cost data
- o Cost estimates are based on current technology

Detailed assumptions and methodology for DDT&E and each major project element are as follows:

1.2.1.1.1 Systems Management

Percent of total HLLV DDT&E cost. CER based on OAO, Gemini, Lunar Orbiter, SRAM, S-IC, LM, and CSM data used to derive Shuttle 040C estimate. SM = CF x .48 x $(\text{Total Cost})^{.65}$. Use complexity factor (CF) of 1.0 for DDT&E and 15 for Production and Operations.

1.2.1.1.2 Systems Engineering and Integration

Percent to total HLLV DDT&E cost based on Shuttle 040C estimate. Complexity if 3x's relative to Systems Management.

TABLE X-D-3 HLLV PROGRAM COST SUMMARY

($\overline{M}$ OF '77 $)

		DDT&E	TFU
1.2.1.1	Total HLLV	(13764)	(1188)
1.2.1.1.1	Systems Management	232	0
1.2.1.1.2	Systems Engr. & Integ.	696	0
1.2.1.1.3	Orbiter	3830	308
1.2.1.1.4	Main Engine (Orb.)	630	210
1.2.1.1.5	Booster	4730	414
1.2.1.1.6	Main Engine (booster)	2362	256
1.2.1.1.7	Flight Test	257	0
1.2.1.1.8	Systems Support	1027	0
1.2.1.1.9	Operations Phase	--	0

TABLE X-D-4 HLLV ORBITER COST SUMMARY

($\overline{M}$ of '77 $)

		DDT&E	TFU
1.2.1.1.3	Orbiter	(3830)	(308)
1.2.1.1.3.1	Project Management	92	0
1.2.1.1.3.2	Systems Engr. & Integ.	276	0
1.2.1.1.3.3	Structures	1198	124
1.2.1.1.3.4	Thermal Protection	860	105
1.2.1.1.3.5	Propulsion Feed	364	7
1.2.1.1.3.6	Power	45	5
1.2.1.1.3.7	Avionics	341	27
1.2.1.1.3.8	ECLS	0	0
1.2.1.1.3.9	Inst'l, Assy. & C/O	120	40
1.2.1.1.3.10	Major Ground Test	114	0
1.2.1.1.3.11	Tooling	419	0

SEI = CF x 1.44 x (Total Cost) $^{.65}$ Use CF = 1 for DDT&E and .5 for Production and Operations.

1.2.1.1.3 <u>Orbiter</u>

- Project Management: Percent of total Orbiter DDT&E. Same CER as above.

- Project Engineering & Integration: Percent to total Orbiter DDT&E. Same CER as above.

- Structures: Divided estimate into airframe and tank. Use Shuttle Orbiter 040C structure CER (C-5A technology) for the airframe. AMPR weight equals 255, 185 LB. Aerospace STS Body/Tank CER (S-IVB and S-II technology) was used to estimate the tank.

- Thermal Protection System: Flame Whield estimated with Aerospace STS CER for Aerospace STS CER for aerodynamic surfaces (F-102A, X-15, F-106A, B-58A, F-111A, B-52, B70A, C5A data). Complexity of 1.0 used. Highly Compacted Fibers (HCF) estimated from Shuttle 040C CER derived from Structures CER (.46 exponent) adjusted to RSI complexity. Insulation estimated from Aerospace STS CER based on dynaflex and microquartz data.

- Propulsion: Propulsion Feed estimated from Shuttle 040C CER (S-IVB and S-II data). Input: LH_2 LOX technology and weight equals 3171 LB. Reaction Control estimated from Aerospace STS CER (Gemini RCS and OAMS data). Input: Weight - 5678 LB. and monopropellant technology. Assume new development.

- Power: Shuttle 040C estimate. Assume APU system. Input: Weight - 2105 LB. and storable propellant technology.

- Avionics: Shuttle 040C estimate. Assume 1980 technology (50% benefit). Input: Weight - 6718 Lb.

- Installation, Assembly & Checkout: Estimated from Shuttle 040C CER (Atlas, Centaur, S-3A, Gemini, CSM, and LM data) as 15% of total Theoretical First Unit (TFU).

- Major Ground Test: Percent of Total hardware DDT&E based on Shuttle 040C estimate (Grumman, McDonnell Douglas, and Rockwell Phase B estimates). MGT = CF x 8.8 x (TC) .65; CF = .8.

- Tooling: Shuttle 040C CER (S-IVB, B-70, and 747 technology). Input: Weight = 498,652 Lb. IT = CF x .000842 x (AMPR) .76 x $25; CF = 1

1.2.1.1.4 <u>Main Engine (Orbiter)</u>: Estimated from POP 76-2 data for Air Force Production (current plan). All new installation development design is included in Main Propulsion Feed System. No new engine design assumed. Fourteen (14) engines per ship set.

1.2.1.1.5 Booster: Estimate without engine is scaled-up from the Orbiter estimate using a .5 exponent for DDT&E and .7 for TFU. Input: Booster weight = 814.562 Lb without engine.

1.2.1.1.6 Booster Main Engine: Estimate from Aerospace STS CER (RL-10A, J-2 data). Assumed all new development of Propane Engine using LH_2/LOX technology. Input: Thrust = 1,916,290 Lb. (vac) per engine. Sixteen (16) engines per ship set.

1.2.1.1.7 Flight Test: Assume flight test program similar to Shuttle (1 year duration, and 6 flights), but no horizontal flight test. Estimate by percent of total hardware DDT&E. Used 2% from Shuttle 040C estimate as a basis.

$FT = CF \times .59 \times (TC)^{.65}$; CF = 1

1.2.1.1.8 Systems Support: Percent of total hardware DDT&E. Based on 15% for GSE and Logistics for Shuttle 040C estimate. Scaled down by .65 exponent. CSM data used to derive 15%. SS = CF x 2.35 X (Total Cost) .65

1.2.1.2 Fuel Per Flight

The estimate for LH_2 (36/Lb) and LOX (2.1/Lb) is based on a study by R. K. Allgeier and Hoyt McBryar. The assumptions are as follows:

- o Current Technology
- o Use Wyoming Coal
- o No learning for Production
- o Government borrows money at 7 1/2 % interest to fund facilities
- o Plant pays no income tax
- o Plant sells 1/2 by-products
- o Coal costs $11.25/MT
- o Use middle band for labor and maintenance costs

Losses for LOX and LH_2 were assumed to be an additional 56% and 8%, respectively. LH_2 losses are minimized by utilizing a reliquification plant.

1.2.1.3 Launch Operations

The launch operations estimate is based on KSC Launch and Landing CER's. Manpower is a function of vehicle flows (number of vehicles being processed at a given time). Vehicle flows was calculated each year using the mission model flight rates, vehicle processing time, and 50 work weeks per year. Turnaround time of 12 days (1 day in flight and 11 days on the ground) was assumed. The KSC CER's included both launch and recovery operations combined; a 10:1 manpower split was assumed. Manyear rates were $24,114; $56,577; and $19,859 for Direct Vehicle Support, Technical Representatives, and Ground System Support, respectively (in 1977 $).

1.2.1.4 Recovery Operations

See launch operations. Cost/flight = (1/11) x KSC CER's launch and landing total. Recovery time is assumed to be one (1) day.

1.2.1.5 Refurbishment

The HLLV lifetime is assumed to be 300 missions. The refurbishment costs are approximately 14% of the average unit cost/flight in 1977 dollars. This number is based on an Air Force study which recommends 15% initial spares and 1.7% vehicle/year sustaining spares for the Shuttle Program.

1.2.2 Cargo Orbital Transfer Vehicle

(Garland Bauch, LS/Schedules Integration Office)

1.2.2.1 Vehicle

The COTV estimate is based on the LH_2 Thermal Electric ARC Jet concept shown in Table VI-D-1-6 of Reference 1. Table X-D-5 shows the summary cost estimate.

General ground rules are identical to the HLLV except as follows:

- O Assume .5 ground test units and one (1) flight test units are included in DDT&E.

TABLE X-D-5 COTV COST SUMMARY

($\overline{M}$ OF 1977 $)

		DDT&E	TFU
1.2.2.1	COTV	(1655)	(128)
1.2.2.1.1	Systems Management	29	0
1.2.2.1.2	Systems Engr. & Integ.	87	0
1.2.2.1.3	Hardware	283	
1.2.2.1.3.1	Structure	205	68
1.2.2.1.3.2	Propulsion	47	1
1.2.2.1.3.3	Power Conditioner	60	37
1.2.2.1.3.4	Other (Contingency)	-	-
1.2.2.1.4	Inst'l, Assy. & C/O	33	22
1.2.2.1.5	Major Ground Test	12	-
1.2.2.1.6	Tooling	792	-
1.2.2.1.7	Systems Support	381	-
1.2.2.1.8	Operations Phase	0	-

- o The flight test unit will be refurbished and used for operations.

Detailed assumptions and methodology for each major project element are as follows:

1.2.2.1.1 Systems Management: See HLLV CER. Use .5 complexity for DDT&E and .25 for Production and Operations.

1.2.2.1.2 Systems Engineering & Integration: See HLLV CER. Use .5 complexity for DDT&E and .25 for Production and Operations. Low complexity based on fewer systems and simpler structures on COTV relative to HLLV.

1.2.2.1.3 Hardware

- Structure: Estimate was scaled from the Satellite Collection System Support Structure cost (444/KG DDT&E and $3.5/KG TFU) and weight, 2.3 M KG.

- Input: 410K Lb and truss configuration. Propellant tanks: estimated from JSC derived Shuttle External Tank CER (S-IVB, S-II, and S-IC data). Assumed .5 complexity and eight (8) tanks per COTV. Weight per tank = 283,750 Lb. w/o propellant.

- Propulsion: Thruster estimate from JSC derived CER's (Gemini RCS & OAMS, Apollo CM and SM RCS, and S-IVB APS data). Assumed Thermal ARC Jet is existing technology, Used 50% of new development to design for space application. Installation design costs are in structure and propellant tanks. Assumed 50 LBF thrust per engine, and 112 engined per COTV.

- Power Conditioner: Used Boeing data, $50/KW and $.73 \times 10^9$ watts from "Reference 1" to obtain unit cost. Used TFU estimate for Design and Development to modify existing technology for space.

1.2.2.1.4 Installation, Assembly, and Checkout: See HLLV CER. User 1.5 complexity since work will be done in space.

1.2.2.1.5 Major Ground Test: See HLLV CER. Use .5 complexity since there are fewer systems to test relative to HLLV.

1.2.2.1.6 Tooling: See HLLV CER. Use .5 complexity due to space operations. Includes machines for ground fabrication of parts only. AMPR Weight equals 2.68 M Lb.

1.2.2.1.7 Systems Support: See HLLV CER. Use complexity of .5 because of fewer systems relative to HLLV.

1.2.2.2 Fuel per Flight

See WBS 1.2.1.2 Fuel per Flight for the data source. LH_2 cost = 10,320,000 Lb x .36 = $3.715 M/flt. (includes unusable propellant). Losses at 18.8% = $698 K/flt. Total cost = $4.413 M/flt. Does not include tanker loss at ground launch pad (8%).

1.2.2.3 Refurbishment

The COTV life is assumed to be one (1) mission to GEO. The structure and propulsion system used to transfer the solar panel must be utilized in GEO if any economic return is to be realized. This assumption places a very stringent cost requirement on the HLLV flights required. It appears logical to study methods to bring the thermal electric arc jet propulsion system and structure back to LEO for reuse. However, additional propellant and propulsion hardware is required.

1.2.3 Personnel Launch Vehicle

(Garland Bauch, LS/Schedules Integration Office)

1.2.3.1 Vehicle

The PLV estimate is based on the EDIN 0505 (F-1 engines in LRB) and EDIN 0511 (New Propane/LOX engines in LRB) configurations. Tables X-D-6-8 shows the summary cost estimates.

General ground rules are identical to those for the HLLV except as follows:

- One (1) ground test unit and one (1) flight test unit are in DDT&E.
- The flight test unit will be refurbished and used during operations.

Detailed assumptions and methodology for each major project element are as follows:

1.2.3.1.1 Systems Management: See HLLV CER. Complexity = .5 relative to HLLV because Orbiter and ET units are existing.

1.2.3.1.2 Systems Engineering & Integration: See HLLV CER. Complexity = .5. Orbiter and ET integration is already complete at PLV time-frame.

1.2.3.1.3 Orbiter: The DDT&E and TFU estimate is based on the Shuttle 040C agency commitment data. No new design and development was assumed except to accommodate changes (approximately 25%) in the Avionics and Power systems. Power D&D = .25 x 149 M = 37 M ('71 $)
= 53 M ('77 $)
Avionics D&D= .25 x 299 M = 75 M ('71 $)
=106 M ('71 $)

Any new test and analysis required to assure vehicle integration is included in Systems Engineering. Assume the Orbiter production line is kept open until 1995. No start-up penalty for production line is included.

1.2.3.1.4 Main Engine (Orbiter): Assume no new engine development is required. Engine first unit is $15 M ('77 $) based on POP 76-2 (current plan) data. The price ($189.715 M) for nine (9) Air Force production engines bought between FY 81 and FY 85 was deflated at an annual rate of 6% to 1977 constant year dollars. No learning is assumed for test engine buys. Assume the engine production line is kept open.

TABLE X-D-6 PLV COST SUMMARY

($\overline{M}$ of 1977 Dollars)

		DDT&E	TFU
1.2.3.1	PLV w/F-1	(2359)	(339)
1.2.3.1.1	Systems Management	68	0
1.2.3.1.2	System Engr. & Integ.	136	0
1.2.3.1.3	Orbiter	537	190
1.2.3.1.4	Main Engine (orb.)	90	45
1.2.3.1.5	External Tank	42	11
1.2.3.1.6	Liquid Repl. Booster	1016	71
1.2.3.1.7	LRB Engine (F-1)	307	22
1.2.3.1.8	Systems Support	163	0
1.2.3.1.9	Operations Phase	--	0

TABLE X-D-7 PLV COST SUMMARY

($\overline{M}$ OF '77 DOLLARS)

		DDT&E	TFU
1.2.3.1	PLV w/Propane/LOX	(3937)	(365)
1.2.3.1.1	Systems Management	112	0
1.2.3.1.2	Systems Engr. & Integ.	232	0
1.2.3.1.3	Orbiter	537	190
1.2.3.1.4	Main Engine (Orb.)	90	45
1.2.3.1.5	External Tank	30	11
1.2.3.1.6	LRB	1016	71
1.2.3.1.7	LRB Engine (Propane/LOX)	1690	48
1.2.3.1.8	Systems Support	230	0
1.2.3.1.9	Operational Phase	--	--

TABLE X-D-8 PLV COST SUMMARY

($\overline{M}$ OF '77 $)

		D&D	TFU
1.2.3.1.6	LRB w/o Engine	(874)	(71)
1.2.3.1.6.1	Project Management	32	0
1.2.3.1.6.2	Systems Engr. & Integ.	56	0
1.2.3.1.6.3	Hardware	(666)	(62)
1.2.3.1.6.3.1	Structure	398	29
1.2.3.1.6.3.2	Thermal Protection	18	3
1.2.3.1.6.3.3	Separation & Recovery	74	1
1.2.3.1.6.3.4	Propulsion Feed	98	14
1.2.3.1.6.3.5	Power	46	5
1.2.3.1.6.3.6	Avionics	32	10
1.2.3.1.6.4	Inst'l, Assy, & C/O	--	9
1.2.3.1.6.5	Major Ground Test	27	0
1.2.3.1.6.6	Tooling	93	0

DDT&E = 874 + (2 x 71) = $1016 M

1.2.3.1.5 External Tank: Assume no new tank development is required except for interface changes (10%) at the ET/LRB and removal of the ET/SRB attach. Use the Shuttle 040C ET estimate as baseline. Thus, ET D&D - .10 x 69 M - 6.9 M ('714) - 9.8 M ('77$). Unit cost = 71. M ('71$) = 10 M ('77$). The ET production line should still be open in 1995 and no start-up penalty is anticipated. Cost for resizing the tank is estimated to be 15 M ('77$) based on a weight change of 3,242 lb and the Shuttle 040C ET CER. Unit Cost also increases by 1.2 M ('77$) due to the size increase. Thus, in round figures, the total D&D = 25 M ('77$) and First Unit - 11 M ('77$).

1.2.3.1.6 Liquid Replacement Booster (LRB):

- Project Management: See HLLV CER. Use CF = 1.
- Systems Engineering & Integration: See HLLV CER. Use CF = 1.
- Hardware

  Structures: Used Aerospace STS Body/Tank Structure CER (Titan III, S-IVB and S-II adjusted, and S-IC technology). Use CF = 1. Weight = 116,917 Lb.

  Thermal Protection: Used Aerospace STS insulation CER (dynaflex and microquartz data base). CF = 1. WT. = 2305 Lb.

  Separation and Recovery: Used SRB recovery system CER's generated at JSC for the MSFC SRB SEB in 1973. Weight = 16,847 Lb.

  Propulsion Feed: See HLLV CER. CF = 1. Weight =38,796 Lb.

  Power: Assume APU monopropellant system. Weight = 873 Lb. Used Shuttle 040C estimate. Assumed no saving for existing technology and smaller system.

  Avionics: Used Aerospace STS Instrumentation and Electrical Distribution CER's (Apollo LM and CSM data) CF = 1; Weight = 1520 Lb. Assume 1 to 3 split in weight.

- Installation, Assembly, and Checkout: See HLLV CER. CF = 1.

- Major Ground Test: See HLLV CER. Assume CF - .5 because LRB has fewer systems than HLLV.

- Tooling: See HLLV CER. Weight - 110,001 Lb. CF = 1.

1.2.3.1.7 LRB Engine (F-1): The F-1 engine production line start-up is assumed to cost 30% of the original development cost. Aerospace STS says F-1 engine development was $550 M (-69$). Thus LRB F-1 - .30 x 550 - 165 M ('69$) -263 M ('77$). The installation design cost is included under the MPS feed system. First Unit cost - 3.5 M ('69$). One (1) ship set of four (4) engines equals 22 M ('77$).

1.2.3.1.7A <u>LRB Engine (Propane/LOX)</u>: The Propane/LOX engine is assumed to be all new development. The estimate is based on the Aerospace STS Rocket Engine CER. LH_2/LOX complexity was assumed. Data base is RL-10A-3 and J-2 engine technology.

1.2.3.1.8 <u>Systems Support</u>: See HLLV CER. Assume CF - .5 because existing Orbiter and ET GSE may be used. SS- CF x 2.35 x (TC) .65.

1.2.3.2 Fuel per Flight (PLV)

See the HLLV fuel per flight WBS 1.2.1.2 for the data source. Cost of RP-1 for the F-1 engine is 27.5 per lb. RP-1 is assumed to have no loss.

The PLV with Propane/LOX LRB engines has a propane fuel cost of 25¢/lb without losses. Propane is assumed to have no losses.

1.2.3.3 <u>Launch Operations (PLV)</u>

See WBS 1.2.1.3 HLLV Launch Operations. Processing time is assumed to be 11 days. Launch to launch time per vehicle is 12 days.

1.2.3.4 <u>Recovery Operations</u>

See HLLV Recovery Operations under WBS 1.2.1.4; assume three (3) days for recovery operations of liquid Replacement Booster since it does not fly back and land. Thus, Cost = (3/11) x KSC Launch and Landing Cost.

1.2.4 <u>Personnel Orbital Transfer Vehicle (POTV)</u>

(Garland Bauch, LS/Schedules Integration Office)

1.2.4.1 <u>Vehicle</u>

The POTV estimate is based on weight/technical characteristics from Section VI-E in vol. II, "reference 1." Tables X-D-9-13 show the summary cost estimates.

General ground rules are the same as for HLLV except as follows:

- o One (1) ground test unit and two (2) flight test units are in DDT&E.
- o Two (2) flight test units will be refurbished and used during operations.

Detailed assumptions and methodology for each major project element are as follows:

1.2.4.1.1 <u>Systems Management</u>: Same as HLLV CER. CF = .4

1.2.4.1.2 Systems Engineering & Integration: Same as HLLV CER. CF = .4

1.2.4.1.3 <u>Crew Module</u>:

- Project Management: Same as HLLV CER. CF = .4.
- Project Engineering & Integration: Same as HLLV CER. CF = .4 because there are fewer systems to integrate.
- Hardware

TABLE X-D-9 POTV COST SUMMARY

($\overline{M}$ OF '77$)

		DDT&E	TFU
1.2.4.1.	POTV	(2204)	(89)
1.2.4.1.1	Systems Management	28	0
1.2.4.1.2	Systems Engr. & Integ.	86	0
1.2.4.1.3	Crew Module	524	28
1.2.4.1.4	Resupply Module	235	7
1.2.4.1.5	Crew Rotation Module	287	13
1.2.4.1.6	Second Stage	328	20
1.2.4.1.7	First Stage	339	21
1.2.4.1.8	Flight Test	44	0
1.2.4.1.9	Systems Support	332	0
1.2.4.1.10	Operations Phase	---	0

TABLE X-D-10 POTV COST SUMMARY

($\overline{M}$ OF '77 $)

		DDT&E	TFU
1.2.4.1.3	Crew Module	(524)	(28)
1.2.4.1.3.1	Project Management	11	0
1.2.4.1.3.2	Systems Engr. & Integ.	31	0
1.2.4.1.3.3	Hardware	(439)	(24)
1.2.4.1.3.3.1	Structure	159	13
1.2.4.1.3.3.2	Power	30	2
1.2.4.1.3.3.3	Avionics	171	4
1.2.4.1.3.3.4	Environmental Control	79	5
1.2.4.1.3.4	Inst'l, Assy, and Checkout	12	4
1.2.4.1.3.5	Major Ground Test	18	0
1.2.4.1.3.6	Tooling	13	0

TABLE X-D-11 POTV COST SUMMARY

($\overline{M}$ OF 1977 $)

		DDT&E	TFU
1.2.4.1.4	Resupply Module	(235)	(7)
1.2.4.1.4.1	Project Management	9	0
1.2.4.1.4.2	Systems Engr. & Integ.	16	0
1.2.4.1.4.3	Hardware	(177)	(7)
1.2.4.1.4.3.1	Structure	177	6
1.2.4.1.4.3.2	Environmental Control	0	0
1.2.4.1.4.4	Inst'l, Assy, & C/O	3	1
1.2.4.1.4.5	Major Ground Test	7	0
1.2.4.1.4.6	Tooling	23	0

TABLE X-D-12 POTV COST SUMMARY

(M OF 1977 $)

		DDT&E	TFU
1.2.4.1.5	Crew Rotation Module	(287)	(13)
1.2.4.1.5.1	Project Management	11	0
1.2.4.1.5.2	Systems Engr. & Integ.	20	0
1.2.4.1.5.3	Hardware	(216)	(11)
1.2.4.1.5.3.1	Structure	137	6
1.2.4.1.5.3.2	Life Support	79	5
1.2.4.1.5.4	Inst'l, Assy, & Checkout	6	2
1.2.4.1.5.5	Major Ground Test	9	0
1.2.4.1.5.6	Tooling	25	0

TABLE X-D-13 POTV COST SUMMARY

(M OF 1977 $)

		DDT&E		TFU	
1.2.4.1.6	Second/First Stage	(328)	(339)	(20)	(21)
1.2.4.1.6.1	Structures	80	80	3	3
1.2.4.1.6.2	Thermal Control	12	12	2	2
1.2.4.1.6.3	Propulsion	131	(142)	6	(7)
1.2.4.1.6.4	Power	23	23	1	1
1.2.4.1.6.5	Avionics	54	54	4	4
1.2.4.1.6.6	ECLS	0	0	0	0
1.2.4.1.6.7	Inst'l Assy & Checkout	12	12	4	4
1.2.4.1.6.8	Major Ground Test	10	10	0	0
1.2.4.1.6.9	Tooling	6	6	0	0

Note: Assume commonality with 1st Stage. WBS 1.2.4.1.7

First Stage cost summary is identical except for propulsion.

Structure: Estimate from Aerospace STS Body/Tank CER adjusted with Apollo LM Ascent Stage data. Input: Weight = 5571 Lb and LM technology.

Power: Assume only batteries and power distribution. The fuel cells are located in the 2nd stage. Estimate based on Aerospace STS Electric Power CER (Gemini, Apollo LM and CSM data). No battery development is assumed. Battery unit cost is $190/Lb (69$). Weight = 100 Lb batteries and 186 Lb distribution.

Avionics: Assume major Avionics components (GN&C, Communications, and Tracking) are in the 2nd stage. Weight - 363 Lb includes only instrumentation and controls. Estimate based on Aerospace STS Instrumentation/ Panels CER (Apollo LM and CSM data).

Environmental Control: Assume Apollo LM aNd CSM technology. Estimate based on Aerospace STS ECS CER. Weight - 290 Lb.

- Installation, Assembly, and Checkout: Same as HLLV.
- Major Ground Test: Same as HLLV Orbiter except CF - .5 because there are fewer systems to test.
- Tooling: Same as HLLV.

1.2.4.1.4 Resupply Module

- Project Management: Same as HLLV CER. CF - .5 relative to Crew Module
- Systems Engineering & Integration: Same as HLLV CER.
- Hardware

Structure: Estimate from Aerospace STS Body/Tank CER.
Weight - 13,230 Lb (Titan III, S-II, SIC, and S-IVB data).

- Installation, Assembly, and Checkout: Same as HLLV CER.
- Major Ground Test: Same as HLLV CER. CF = .4 relative to HLLV. No systems to test except structure.
- Tooling: Same as HLLV except .8 complexity relative to HLLV structure. Weight - 13,230 Lb.

1.2.4.1.5 Crew Rotation Module

- Project Management: Same as HLLV CER. CF = .6
- Systems Engineering & Integration: Same as HLLV. CF = .4
- Hardware

Structure: Used Aerospace STS Body/Tank CER. Assumed .5 complexity.
Weight - 41.895 Lb

Life Support: Same as Crew Module System.

- Installation, Assembly, & Checkout: Same as HLLV CER.
- Major Ground Test: Same as HLLV CER. CF = .4.
- Tooling: Same as HLLV CER. CF = .4 Weight = 41,895 Lb.

1.2.4.1.6 Second Stage

- Structures: Used Aerospace STS Body/Tank CER. CF - 1.2 for D&D and 1.2 for TFU. Weight = 4850 Lb. Assumed LH_2/LOX technology. Complexity is determined from propellant, materials, and configuration. (F = 2 (propellant) x 1 (material) x .6 (monocoque) = 1.2

- Thermal Control: Used Aerospace STS TPS CER. CF = 1. Insulation cost based on dynaflex and microquartz data Weight = 1180 Lb.

- Propulsion:

  Main Engines: Use 30% of new development, $327 M ('77$), for RL-10 engines D&D. Unit cost from Aerospace STS Rocket Engine CER. CF = 1. Allow for 50% commonality with the 1st stage.

  Main Feed: Same as HLLV CER (SII & S-IVB data) CF = 1. Weight - 1422 Lb.

  Auxiliary Propulsion: See HLLV CER. Assume use of existing monopropellant system. Use 30% of new development for cost. Assume no commonality with 1st stage because of different size. Weight - 2630 Lb.

  Power: Assume existing fuel cell and batteries. Use 20% of new development, $191 M ('77$), from Aerospace STS EPS CER. (Gemini and Apollo SM Technology) Weight - 340 Lb

  Avionics: Based on "Reference 1" estimate from August 31, 1976. Weight = 560 Lb.

- Installation, Assembly, and Checkout: Same as HLLV CER.
- Major Ground Test: Same as HLLV CER. CF = .4
- Tooling: Same as HLLV CER. CG - 1. Assume 50% commonality with 1st stage. Weight = 4850 Lb.

1.2.3.1.7 1st Stage: All cost elements are identical to 2nd Stage except propulsion.

- Propulsion:

  Main Engine: Same development and unit cost assumption as 2nd stage except use 4 engines per ship set instead of 2.

  Main Feed: Same as 2nd stage.

  Auxiliary Propulsion: Same as 2nd stage except smaller. Weight = 480 Lb.

1.2.4.2 Fuel per Flight (POTV)

The POTV propellant cost are 36¢/lb LH_2 and 21¢/LB LOX without losses. See HLLV fule cost WBS 1.2.1.2 for the data source. Losses equal 12.9% LH_2 and 7.3% LOX, preflight + flight lossess, for fueling in low Earth Orbit. GEO refueling losses are 20.4% LH_2 and 12.3% LOX.

1.2.4.3 Refurbishment (POTV)

The POTV mission life is assumed to be 300 flights. Each flight may require up to 1% refurbishment of first unit cost.

TFU

Structural Framework	1 (1975 $'s)
Landing Gear	1 (1975 $'s)
ECS	4 (1970 $'s)
Displays & Controls	3 (1977 $'s)

Escalated to 1977 dollars:

SUMMARY OF COSTS

WBS 1.3 FABRICATION AND ASSEMBLY

		DDT&E	PRODUCTION	OPS	TOTAL
1.3.1	SPACE CONSTRUCTION BASE	5257	48785	21594	75636
1.3.2	SATELLITE FABRICATION & ASSEMBLY	1308	5159	2445	8912
1.3.3	ANTENNA FABRICATION & ASSEMBLY	403	2498	1101	4002
1.3.9	MANAGEMENT & INTEGRATION	218	-	-	218
	TOTAL	7186	56442	25140	88768

WBS 1.3.1

SPACE CONSTRUCTION BASE

Analyst: H. W. Whittington

Introduction

Fiaures X-D-3,4&5 contain the work breakdown structure (WBS) for the Space Construction Base (SCB) project. The SCB is the hotel, hospital, factory, restaurant, etc., used by the approximately 600 people working on the Solar Power Satellite. The design for this facility represents a composite of the Rockwell International (RI) and McDonnell-Douglas Phase B. Space Station Studies conducted in 1970, scaled in such a way to be compatible in dimension with the Heavy Lift Launch Vehicle (HLLV). Ground rules and assumptions for the Space Construction Base System are similar to those general ground rules and assumptions for the SPS program. Ground rules for the NASA In-House Hardware, Engineering Support were developed from comments from the various JSC organizational element.

General Costing Methodology

Whenever possible JSC cost estimating relationships were used to estimate subsystem costs. Whenever CER's of any sort were not available, or not determined applicable because of the requirement for large extrapolations, Rockwell and McDonnell-Douglas Phase B Space Station cost estimates were used.

Standard approaches used for scaling were as follows:

1. For DDT&E - a square root scaling factor was used as follows:

$$\left(\frac{\text{Wt SCB}}{\text{WT Phase B Space Station}}\right)^{0.5} \times \text{Cost estimate of Phase B Space Station Subsystem}$$

2. For Theoretical First Unit Cost, the following scaling factor was used:

$$\left(\frac{\text{Wt SCB}}{\text{Wt Phase B Space Station}}\right)^{0.75} \times \text{Cost estimate of Space Station Subsystem}$$

The above factors are typical throughout the Aerospace community. The exponent of 0.75 is used for production because while engineering, manufacturing, quality, etc. increase at the same rate as DDT&E, $\left(\frac{Wt}{Wt}\right)^{0.5}$, material costs increase directly with the increase in weight.

Identification of the data points were removed from the CER's within this section because some of the data used were taken from sensitive contractor reports. Copies of the original CER's are available in the Resources Management Office, Code BV.

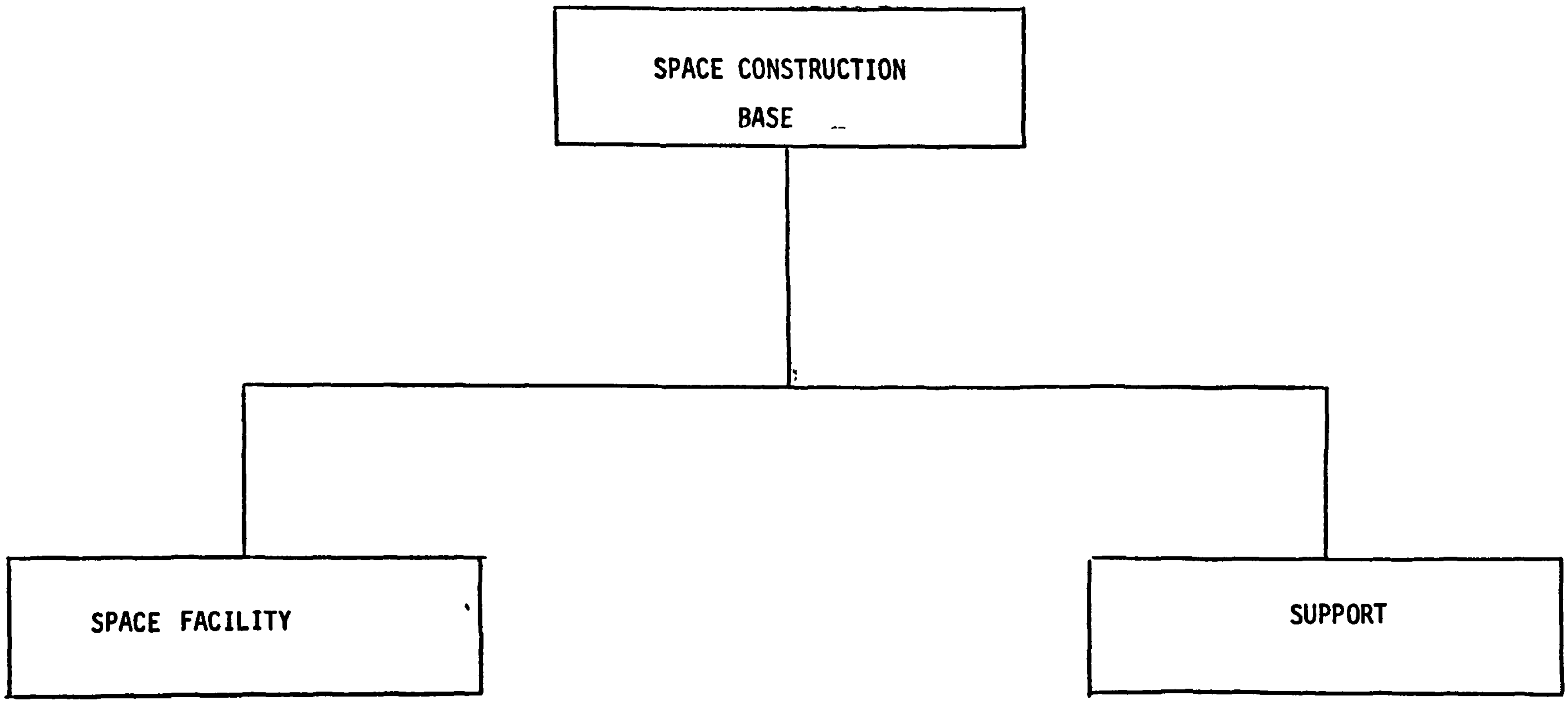


FIGURE X-D-3

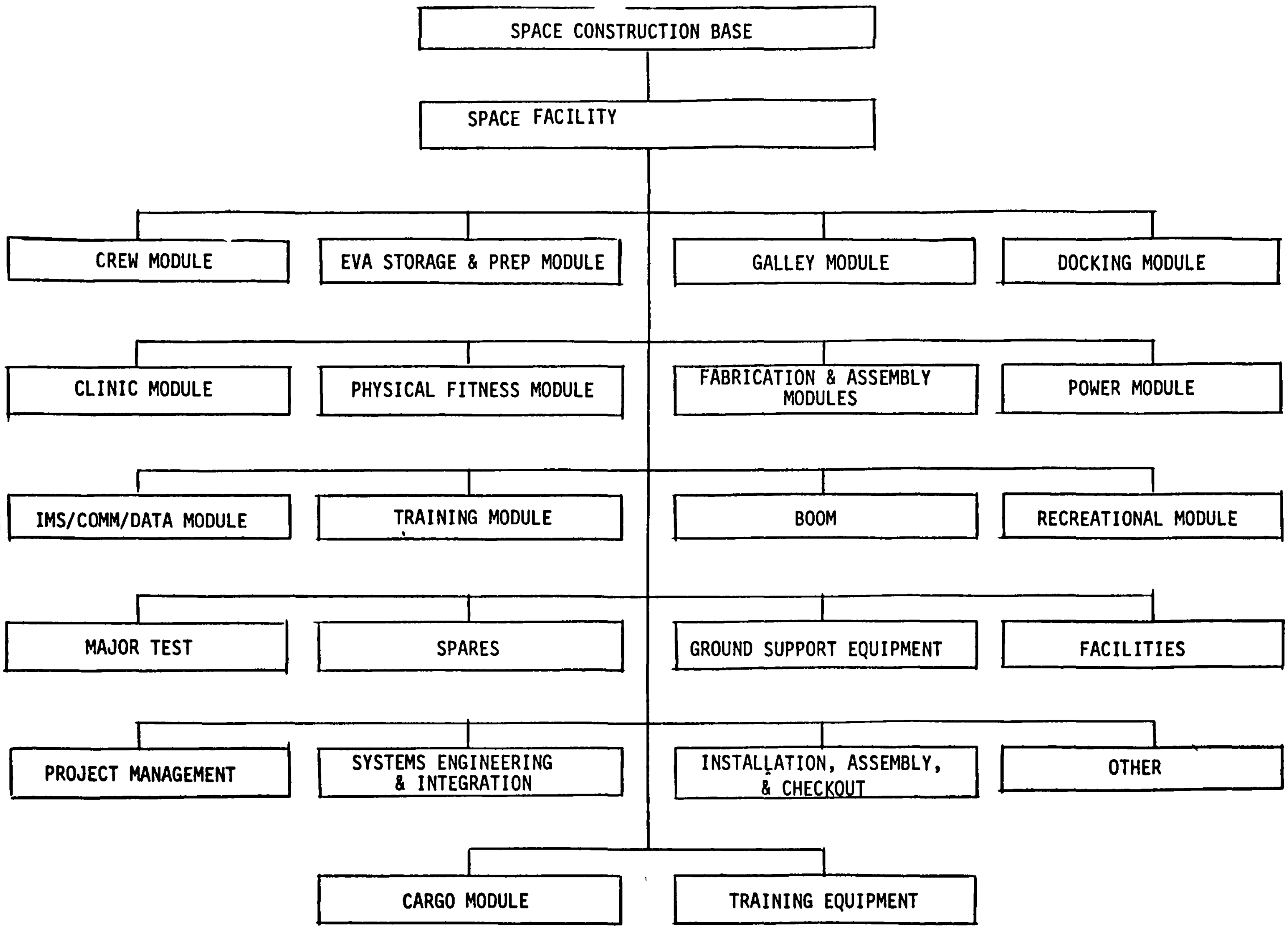

SPACE CONSTRUCTION BASE
SPACE FACILITY
CREW MODULE
EVA STORAGE & PREP MODULE
GALLEY MODULE
DOCKING MODULE
CLINIC MODULE
PHYSICAL FITNESS MODULE
FABRICATION & ASSEMBLY MODULES
POWER MODULE
IMS/COMM/DATA MODULE
TRAINING MODULE
BOOM
RECREATIONAL MODULE
MAJOR TEST
SPARES
GROUND SUPPORT EQUIPMENT
FACILITIES
PROJECT MANAGEMENT
SYSTEMS ENGINEERING & INTEGRATION
INSTALLATION, ASSEMBLY, & CHECKOUT
OTHER
CARGO MODULE
TRAINING EQUIPMENT

FIGURE X-D-4

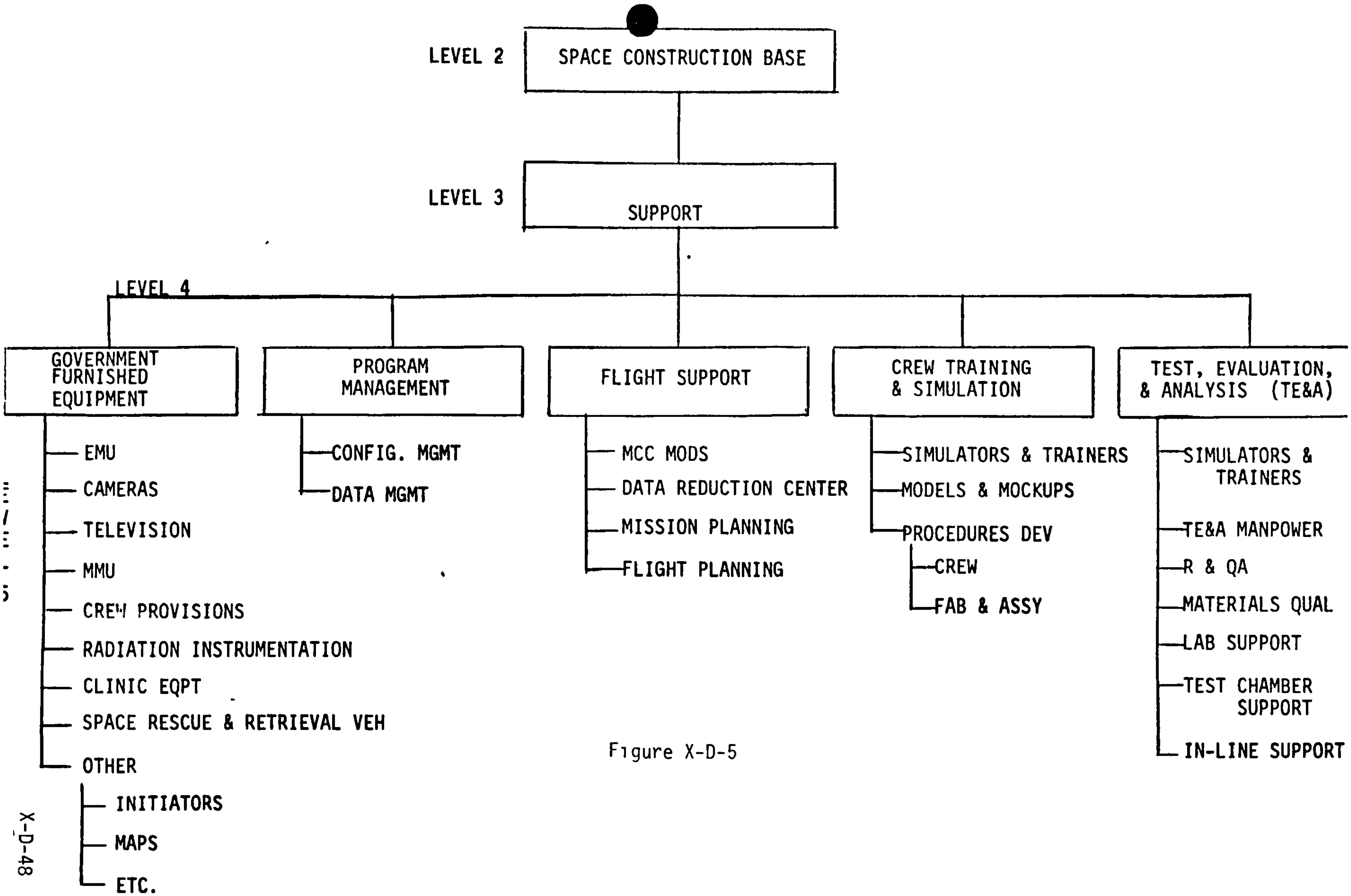

LEVEL 2
SPACE CONSTRUCTION BASE
LEVEL 3
SUPPORT
LEVEL 4
GOVERNMENT FURNISHED EQUIPMENT
EMU
CAMERAS
TELEVISION
MMU
CREW PROVISIONS
RADIATION INSTRUMENTATION
CLINIC EQPT
SPACE RESCUE & RETRIEVAL VEH
OTHER
INITIATORS
MAPS
ETC.
PROGRAM MANAGEMENT
CONFIG. MGMT
DATA MGMT
FLIGHT SUPPORT
MCC MODS
DATA REDUCTION CENTER
MISSION PLANNING
FLIGHT PLANNING
CREW TRAINING & SIMULATION
SIMULATORS & TRAINERS
MODELS & MOCKUPS
PROCEDURES DEV
CREW
FAB & ASSY
TEST, EVALUATION, & ANALYSIS (TE&A)
SIMULATORS & TRAINERS
TE&A MANPOWER
R & QA
MATERIALS QUAL
LAB SUPPORT
TEST CHAMBER SUPPORT
IN-LINE SUPPORT

Figure X-D-5

Sizing/Quantity Assumptions

1. Crew Module - The 33' x 52' (44, 250 ft^3) Phase B (1970) Core Module housed 6 crewmen on one of its two decks. It was capable of supporting 12 men for an indefinite period of time. Using both decks for crew quarters it could comfortably house 12 crewmen. The 50' x 100' (196, 250 ft^3) Space Construction Base Module, based upon its volume relationship to the Phase B Core Module, will be capable of housing 50 people. This is equivalent to 5 people living in a 10' x 50' mobile home, which seems pretty posh for a space facility. 12 crew modules will be required to house the 600 man crew in the Space Construction Base. Temporary overflow could be handled by using the clinic module or recreational module for crew quarters.

2. Projected quantities of modules required as follows:

Module	Quantity
Crew Module	12
EVA Storage & Prep Module	1
Cargo Module	4
Galley Module	1
Clinic Module	1
Physical Fitness Module	1
Fabrication and Assembly Module	2
Power Module	1
Information Module	1
Training Module	1
Boom	1
Recreational Module	1
	27

All of the modules are similar except for the boom which is a non-pressurized tunnel running to the solar array and through which the electrical power distribution system runs. A summary of equivalent units for the total complement of 7 SCB's is contained in figure X-D-6.

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT
SUMMARY OF EQUIVALENT UNITS

FIGURE X-D-6

MODULE \ EQUIVALENT PRODUCTION UNITS	STRUCTURE	TOOLING	ECLS	RCS	ENVIRONMENTAL PROTECTION	EPS	IMS/COMM/DATA	STAB/G & C	INST, ASSY & C/O	SYST ENG & INSTAL	PROJECT MGMT	TEST	GSE	TOTAL NUMBER OF MODULES PER SCB	TOTAL NUMBER OF COMPLETE MODULES
CREW MODULE	12	2 LINES	12	12	12	7*	6.0**	12	12	-	-	-	-	12	84
EVA STORAGE & PREP MODULE	1	-	.7	-	1	.5	.5	-	1	-	-	-	-	1	7
CARGO MODULE	4	-	.5	-	4	7*	2.0	-	4	-	-	-	-	4	28
GALLEY MODULE	1	-	.8	-	1	.5	.5	-	1	-	-	-	-	1	7
DOCKING MODULE															
CLINIC MODULE	1	-	.9	-	1	.5	.5	-	1	-	-	-	-	1	7
PHYSICAL FITNESS MODULE	1	-	.8	-	1	.5	.5	-	1	-	-	-	-	1	7
FAB & ASSEMBLY MODULE	2	-	.8	-	2	1*	1.0	-	2	-	-	-	-	2	14
POWER MODULE	1	-	.1	-	1	.5	.5	-	1	-	-	-	-	1	7
COMMAND & DATA MODULE	1	-	.7	-	1	.5	1.0**	-	1	-	-	-	-	1	7
TRAINING MODULE	1	-	.7	-	1	.5	.5	-	1	-	-	-	-	1	7
RECREATION MODULE	1	-	.7	-	1	.5	.5	-	1	-	-	-	-	1	7
BOOM	0.5	-	.1	-	1		.2	-	.4	-	-	-	-	1	7
TOTAL SUBSYSTEMS PER SCB	27	2 LINES	19	12	27	14	14	12	27					27	189
TOTAL SUBSYSTEMS FOR 7 SCB'S	189	2 LINES	133	84	~~189~~	119	98	84	189						

* THE SOLAR ARRAY IS CHARGED TO THE FIRST NEW MODULE. ALL OTHER MODULES ASSUMED TO HAVE 0.5 EPS LOCK

** ON-BOARD COMPUTER ASSUMED TO BE IN COMMAND/DATA MODULE. ALL OTHER MODULES EXCEPT BOOM HAVE 0.5 IMS/COMM/DATA SUBSYSTEMS

3. Calculation of Weights - The ratio of the circumferential area of the 33' D X 52' L module to the 50' D X 100' L module is 5388 to 15700, or 1 to 2.9 All system and subsystem weights in the 33' D station were multiplied by this factor to establish the following weight statement of the Space Construction Base. Obviously this technique leaves something to be desired, especially in areas such as environmental control where volume maintained is such a cost driver, but the technique does preclude design extrapolation at this very early stage of the SPS program. The following weights (table X-D-14) were established for the Standard Module.

Estimated Costs

1.3.1.1. Space Construction Base - Space Facility
1.3.1.1.1 Structure

DDT&E

Approach 1 - By use of figure X-D-7, which implies that the module structure is equivalent to that of a cargo aircraft, an estimate of \$87 M in FY 1970 \$ can be derived. By escalating to FY 1977 \$ using the escalation factors contained in the program ground rules and assumptions, the resulting number is \$156 M. Because of secondary structures, (floors, partitions, etc.) the module structure was considered to be 30% more complex than the cargo aircraft structure, a complexity factor of 1.3 was applied, resulting in an estimate of \$203 M.

Approach 2 - An estimate of \$80 M in FY 1970 \$, or \$144 M in FY 1977 \$ can be derived using the CER which forms figure X-D-8. Application of the 1.3 complexity factor yields an estimate of \$187 M.

Approach 3 - Scaling, by the square root method, of the Rockwell and McDonnell Phase B Space Station estimates yields the following results.

Rockwell Structure Estimate in FY 1970 \$ = \$134 M

Rockwell Structure Estimate in FY 1977 \$ = \$241 M

MDAC Structure Estimate in FY 1970 \$ = \$88 M

MCAC Structure Estimate in FY 1977 \$ = \$158 M

$(2.9)^{0.5}$ X \$241 M = \$433 M, where 2.9 is the weight scaling factor based upon circumferential area (mentioned earlier), and \$241 M is the Rockwell estimate for the 33' X 52' crew module. Using the same technique for the MDAC estimate the following number can be derived.

$(2.9)^{0.5}$ X \$158 = \$269 M

TABLE X-D-14
SPACE CONSTRUCTION BASE
Weight Statement in Lbs.

WBS Element	33' D		SCB
Crew Module			
Structure	36,010		104,429
Primary	31,361		90,947
Secondary	4,649		13,482
Reaction Control	3,350		9,715
Environmental Protection	9,540		27,666
Core Thermal	1,227		3,558
Micrometeroid	1,563		4,533
Aero-Thermal Dynamic	6,750		19,575
Electrical Power	25,585		74,197
Arrays	4,720		13,688
Orientation	286		829
Mounts & Supports	2,434		7,059
Fuel Cells	480		1,392
Plumbing	160		464
Batteries	11,430		33,147
Equipment & Controls	1,813		5,258
Distribution & Wiring	4,262		12,360
ECLSS	15,804		41,540
Atmospheric Storage	1,255		3,640
CO_2 Management	2,099		6,087
Atmospheric Control	2,476		7,180
Active Thermal Control	5,231		15,170
Water Management	1,581		4,585
Waste Management	657		1,905
Personal Hygiene	719		2,085
Food Management	1,483	(4,301)	*
Special Life Support	303		888
Crew & Habitability	2,127		4,800
Personal Equipment	47		136
General Equipment	555		1,610
Furnishings	1,053		3,054
Recreation	472	(1,369)	**
Information	8,000		23,200
Data Processing	1,595		4,626
Displays & Controls	1,630		4,727
Software	985		2,856
Comm & Tracking	3,790		10,991
Guidance & Control	1,740		5,046
Inertia Reference	81		235
Optical Reference	341		989
Control Moment Gyro	1,212		3,515
RCS Electronics	106		307

* In Galley Module
** In Recreational Module

TABLE X-D-14 (Cont'd)

WBS Element	33' D	SCB
Docking Module	3,100	8,990
Passive Ring	2,500	7,250
Active Ring	600	1,740
Boom	3,124	9,060
Primary Structure	1,328	3,851
Secondary Structure	212	615
Env Protection	340	986
Docking	580	1,682
Active Thermal Control	664	1,926

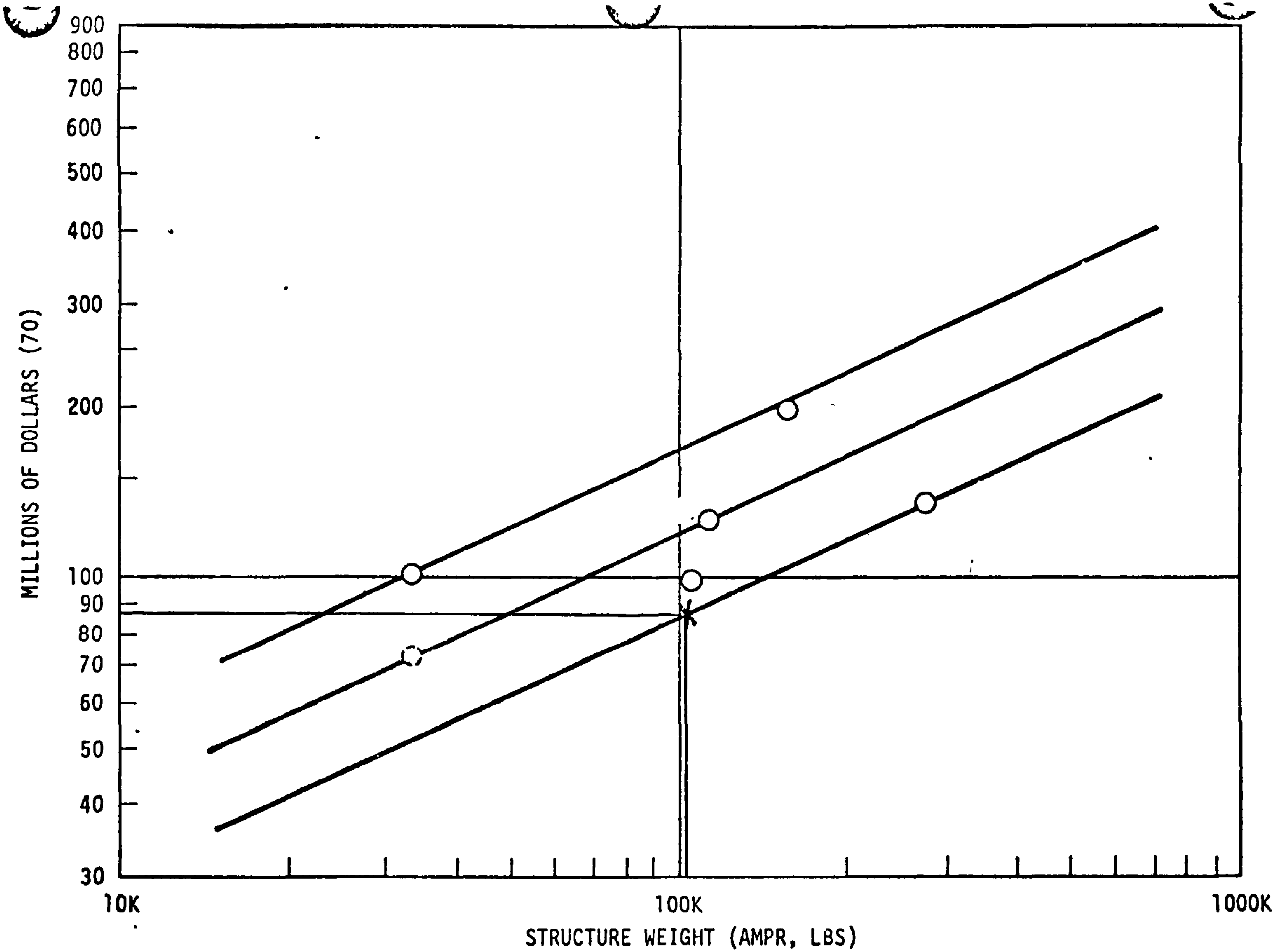


FIGURE X-D-7 STRUCTURAL DESIGN - DEVELOPMENT COST

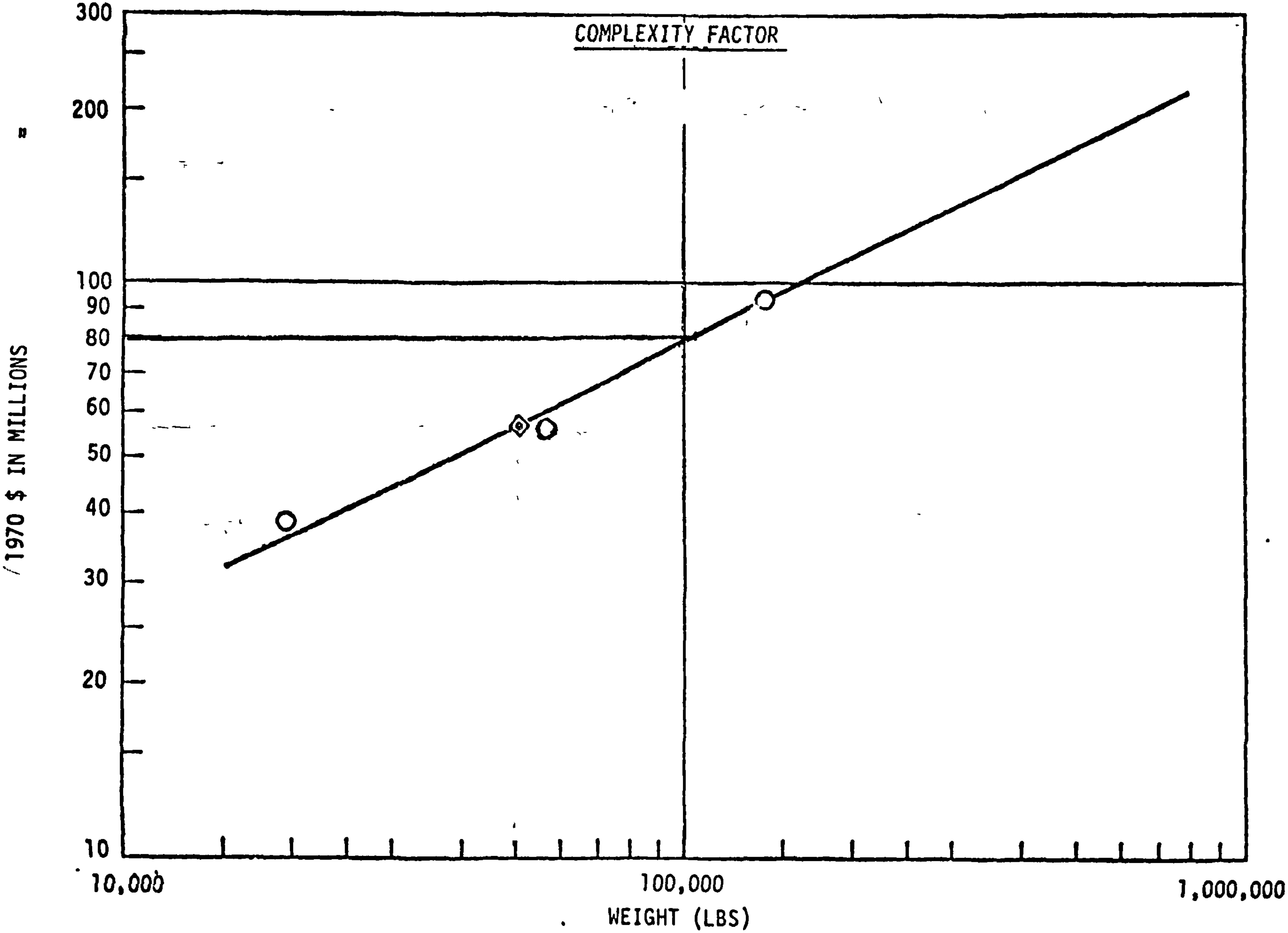


FIGURE X-D-8 BODY/TANK STRUCTURE—DESIGN DEVELOPMENT COSTS

Range of Estimates

JSC CER (Cargo Aircraft Data)	$203 M
JSC CER (Booster Data)	$187 M
Scaling of RI Phase B Estimate	$433 M
Scaling of MDAC Phase B Estimate	$269 M

Estimate Selected - $200 M. The estimates of $203 M and $187 M were developed from the CER's in figures X-D-7 and 8. The higher numbers of $269 M and $433 M were derived from assumed scaling relationships applied to estimates taken from CER's, which is a less desirable approach.

Theoretical First Unit Cost (TFU)

Approach 1. Figure X-D-9 yields a TFU cost of $ 22 M, this figure being taken from the lower complexity line. In real year $ this equates to $40 M. Application of the 1.3 complexity factor results in an estimate of $52 M.

Approach 2. A number of $8 M in 1970 $, or $14 M in 1977 $ can be estimated by using figure X-D-10. This equals $18 M if a 1.3 complexity factor is applied.

Approach 3. Use of the scaling factor approach discussed earlier

Rockwell TFU in 1970 $ - 18.4 M

Rockwell TFU in 1977 $ - 33.0 M

MDAC TFU in 1970 $ - 35.0 M*

MDAC TFU in 1977 $ - 63.0 M

$(2.9)^{0.75} \times 33 \text{ M} = 73 \text{ M}$

$(2.9)^{0.75} \times 63 \text{ M} = 140 \text{ M}$

Estimate Used - $60 M

*Derived from $38 M for 1.1 units

1.3.1.1.2 Environmental Control & Life Support Subsystem

DDT&E

Approach 1 - By using Figure X-D-11, a JSC Cost Estimating Relationship, an estimate of $706 M in FY 1970 $ can be derived. Conversion to FY 1977 $ using the escalation factors contained in the overall ground rules and assumptions results in an estimate of $1224 M.

C-11

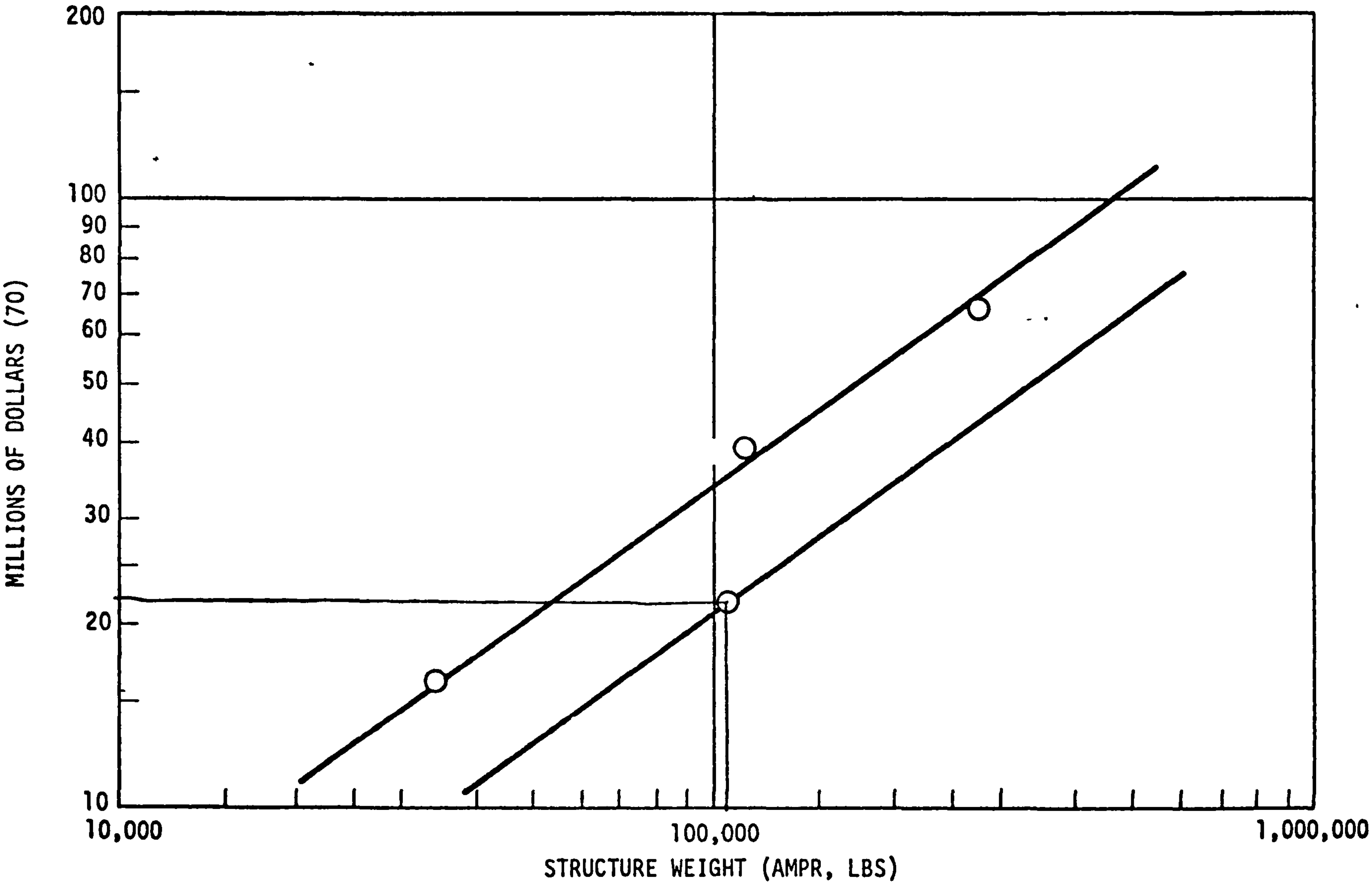


FIGURE X-D-9 STRUCTURE, THEORETICAL FIRST UNIT (TFU) COST

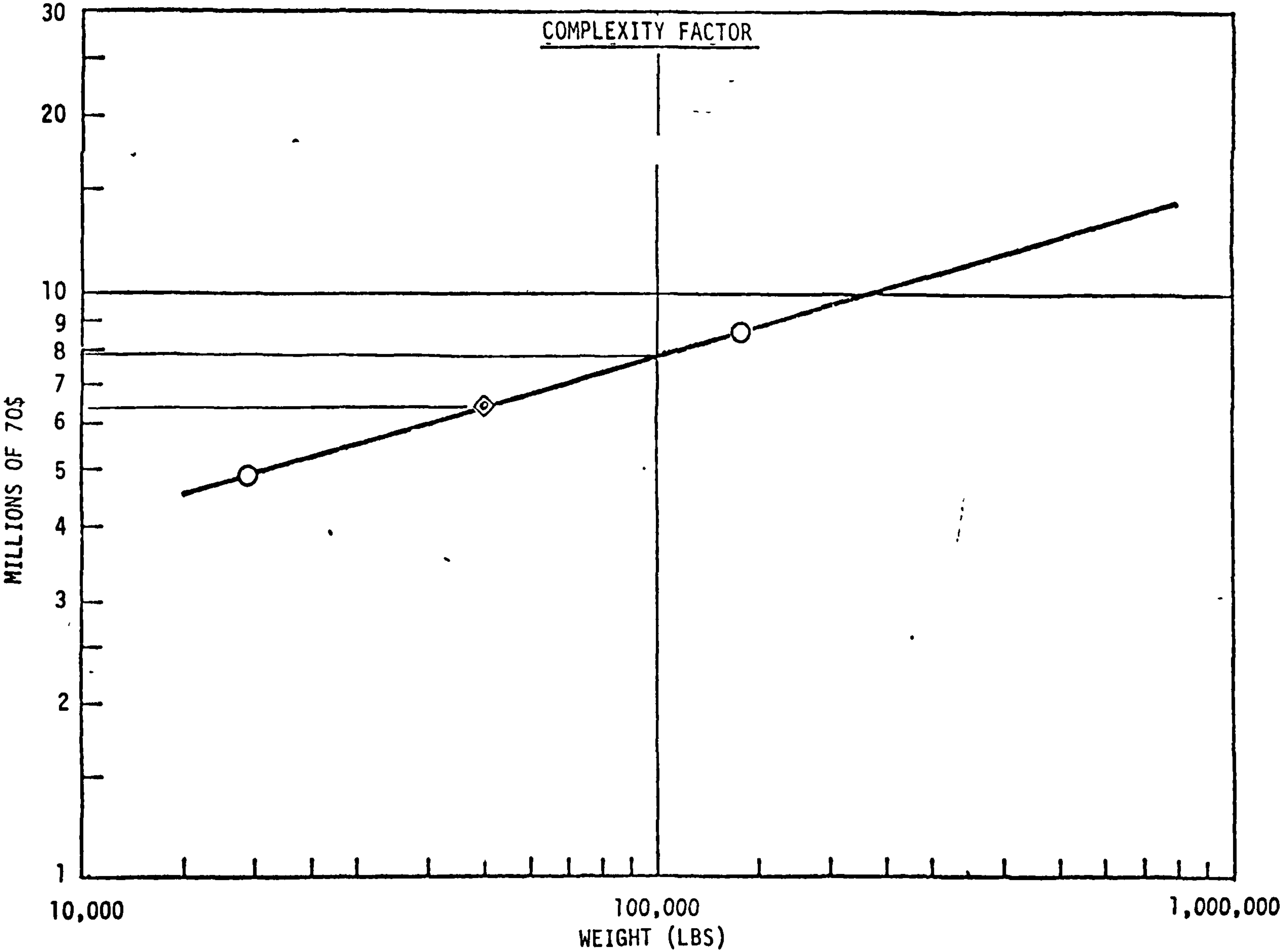
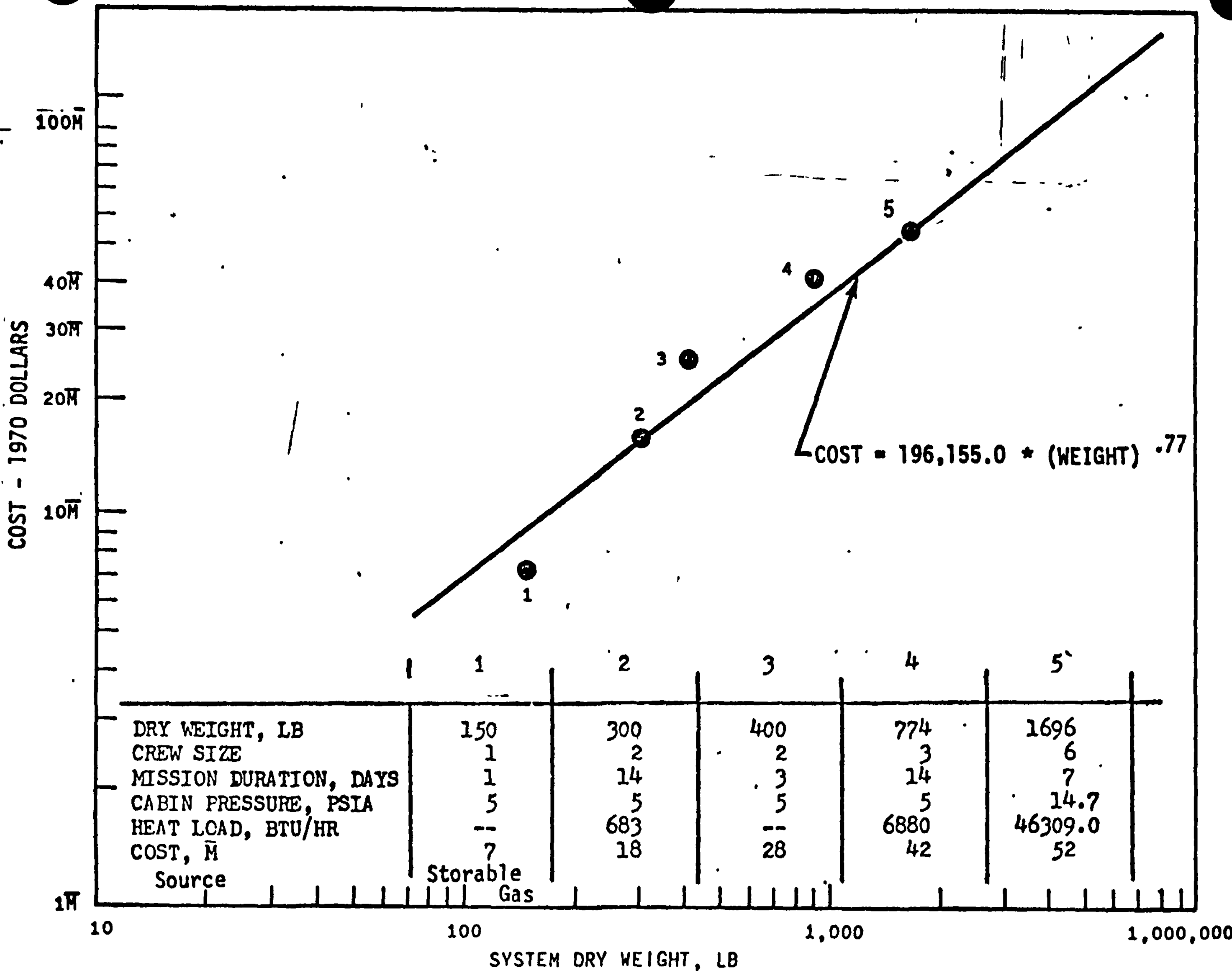


FIGURE X-D-10 BODY/TANK STRUCTURE—FIRST UNIT COST



	1	2	3	4	5
DRY WEIGHT, LB	150	300	400	774	1696
CREW SIZE	1	2	2	3	6
MISSION DURATION, DAYS	1	14	3	14	7
CABIN PRESSURE, PSIA	5	5	5	5	14.7
HEAT LOAD, BTU/HR	--	683	--	6880	46309.0
COST, M̄	7	18	28	42	52
Source	Storable Gas				

FIGURE X-D-11 ECS D&D CER

Approach 2 - The CER's in figures X-D-12 and 13 were developed for MSFC by the Planning Research Corporation (PRC). The following estimate in 1976 $ is the result of using these CER's for a closed ECS system.

$$\text{Design and Development} = 5.623\ (41{,}540)\ \text{lbs})^{0.415} = 464.1$$

$$\text{Major Test Hardware} = 0.282\ (41{,}540)\ \text{lbs})^{0.536} = \underline{84.3}$$

$$548.4$$

To convert from 1976 $ to 1977 $: 548.4 X 1.088 = 597 M

Appraoch 3 - Extrapolate from the Rockwell Phase B estimate using the square root of the weight scaling factor of 2.9.

Rockwell Phase B. Estimate (1970 $ in millions)

ECLSS	219.2
Crew Habitability	19.5
ECLSS Vent System	1.6
	230.3

Conversion to 1977 $ using the escalation assumptions results in an estimate of $413 M.

The following estimate can be derived by using the factors mentioned above:

$$(413) \times (2.9)^{0.5} = 413 \times 1.7 = \underline{\underline{\$702\ M}}$$

<u>Estimate Chosen</u> - $600 M. The PRC CER is the best estimating relationship available today primarily because it contains skylab data. Use of the CER in Appraoch 1 requires extrapolation of data beyond what is reasonable. While the adjusted Rockwell estimate is relatively close to the estimate using the PRC CER, it was based upon only one data point.

<u>Theoretical First Unit Cost</u>

Approach 1 - Use of the JSC CER in figure X-D-14 results in an estimate of $82 M.

Approach 2 - Extrapolation from the Rockwell and McDonnell Douglas Space Station Phase B estimates using the weight scaling factor of (2.9) 0.75 results in estimates of

Rockwell Estimate (1970 $ in millions)

ECLSS	46.9
ECLSS Vent System	1.8

ECLS/CREW ACCOMMODATIONS SUBSYSTEM

FIGURE X-D-12

STEP/EQUATION	EQUATION NAME	EQUATION	CONSTRAINTS
STEP 1 EQUATIONS	Subsystem CERs D&D (Closed System) (Open System) Flight Hardware (Closed System) (Open System)	 $E/CS = 5.623\ WT^{0.415}$ $E/CS = 8.196\ WT^{0.294}$ $E/CS = 0.282\ WT^{0.536}$ $E/CS = 0.592\ WT^{0.385}$	WT = Subsystem Weight (Lbs)
STEP 2 EQUATIONS	Subsystem Element CERs D&D • Atmosphere Mgmt (Closed) (Open) • Water Mgmt (Closed) (Open) • Waste Mgmt • Accommodations	 $SLE_1 = 1.416\ WT^{0.478}$ $SLE_1 = 1.258\ WT^{0.279}$ $SLE_2 = 0.837\ WT^{0.519}$ $SLE_2 = 0.114\ WT^{0.473}$ $SLE_3 = 0.921\ WT^{0.329}$ $SLE_4 = 6.413\ WT^{0.279}$	WT = Subsystem Element Dry Weight (Lbs)
	Flight Hardware • Atmosphere Mgmt (Closed) (Open) • Water Mgmt (Closed) (Open) • Waste Mgmt • Accommodations	 $SLE_1 = 0.088\ WT^{0.611}$ $SLE_1 = 0.014\ WT^{0.665}$ $SLE_2 = 0.121\ WT^{0.587}$ $SLE_2 = 0.0103\ WT^{0.603}$ $SLE_3 = 0.0094\ WT^{0.925}$ $SLE_4 = 0.760\ WT^{0.280}$	
	Subsystem Element Factors	$SLE_i = (E/CS) \times (SEF_i)$	$i = 1, 2, 3, 4, 5$ E/CS = ECLS/Crew Accommodations Subsystem Cost SEF_i = Subsystem Element Factors
STEP 3a EQUATION	Subsystem Spread Factors	$SLE_{ji} = (SLE_i) \times (SF_{ji})$	$i = 1,2,3,4$ j = Module # SF_{ji} = User Developed Spread Factor SLE_i = Subsystem Element Costs
STEP 3b EQUATION	Subsystem Wraparound Factors	$E/CS_j = \left(\sum_{i=1}^{4} SLE_{ji}\right) \times (1 + SW)$	SW = Subsystem Level Wraparound Factor SLE_{ji} = Subsystem Element Cost by Module $E/CS = \sum E/CS_j$

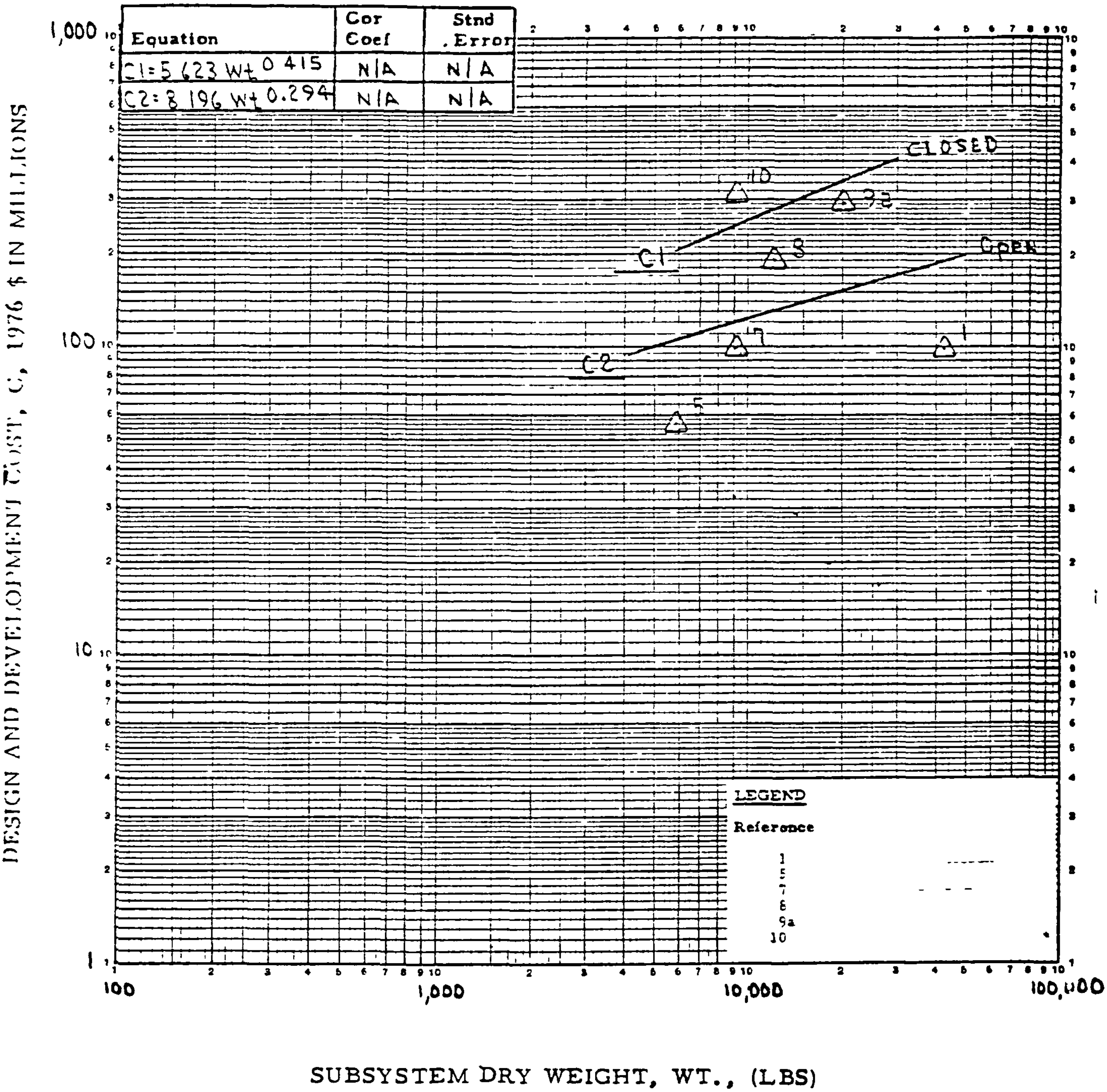
SUBSYSTEM ELEMENT	SUBSYSTEM ELEMENT FACTORS	D&D	Flight Hardware
SLE_1 = Atmosphere Mgmt (Closed)	SEF_1 =	.403	450
SLE_2 = Water Mgmt (Closed)	SEF_2 =	.098	143
SLE_3 = Waste Mgmt	SEF_3 =	018	012
SLE_4 = Accommodations	SEF_4 =	188	.214
SLE_5 = Subsystem Level Wraparound	SEF_5 =	293	181
		1.000	1 000
Subsystem Level Wraparound As a Percent of $\sum_{i=1}^{4} SLE_i$	SW =	414	220

ECLS/CREW ACCOMMODATIONS STEP 1, 2, AND 3 EQUATIONS

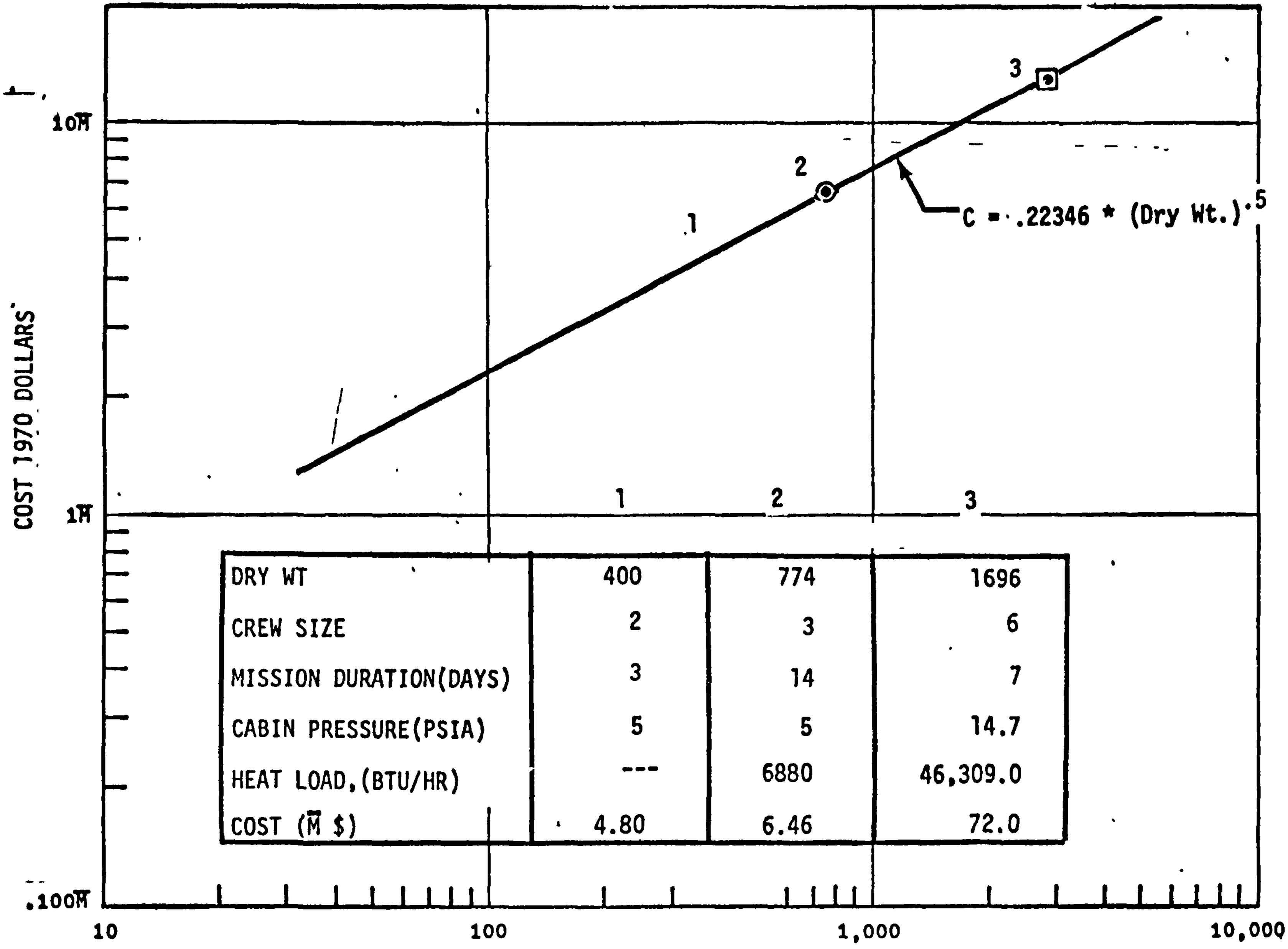
FIGURE X-D-13

ECLS/CREW ACCOMMODATIONS

Equation	Cor Coef	Stnd Error
$C1 = 5.623\ Wt^{0.415}$	N/A	N/A
$C2 = 8.196\ Wt^{0.294}$	N/A	N/A



1.3.5 ENVIRON TAL CONTROL SUBCONTRACT TFU COST



	1	2	3
DRY WT	400	774	1696
CREW SIZE	2	3	6
MISSION DURATION(DAYS)	3	14	7
CABIN PRESSURE(PSIA)	5	5	14.7
HEAT LOAD,(BTU/HR)	---	6880	46,309.0
COST ($\overline{M}$ $)	4.80	6.46	72.0

FIGURE X-D-14 ECS TFU CER

Crew Habitability $\underline{\quad 2.6}$
51.3

Rockwell Estimate in 1977 \$ = 92.1 M

MDAC Estimate in 1970 \$ = \$20 M

MDAC Estimate in 1977 \$ = \$36 M

$(2.9)^{0.75} \times 92 \text{ M} = \$202.4 \text{ M}$

$(2.9)^{0.75} \times 36 \text{ M} = \$\ 79.0 \text{ M}$

Estimate Used - <u>\$80 M</u>

1.3.1.1.3 Reaction Control System

<u>DDT&E</u>

Approach 1 - The derived weight for the SCB RCS in 9,715 lbs. By using the CER used by Rockwell during the Phase B Space Station Study (see figure X-D-15) you arrive at the following estimates in 1970 \$

Major Test Hardware - \$6400/lb X 9715 lbs = \$62.2 M

Design & Development - \$36,000/lb X 9715 lbs = \$350 M or \$412 M in 1970 \$

This escalates to \$740 M in 1977 \$

Approach 2 - Scaling of Gemini and Apollo Block I Stabilization & Control Data

	System Weight	Cost in 1969 \$
Gemini	40	6 M
Appollo Block 1	229	61 M

$$\left(\frac{9715}{40}\right)^{.5} \times \$6 \text{ M} = (249)^{.5} \times 6 \text{ M} = 94 \text{ M}$$

$$\left(\frac{9715}{229}\right)^{.5} \times 61 \text{ M} = (42)^{.5} \times 61 \text{ M} = 398 \text{ M}$$

In 1977 \$ the Gemini extrapolation yields an estimate of \$177 M, while the Apollo Block 1 extrapolation yields an estimate of \$750 M.

Approach 3 - Scaling of Rockwell and McDonnell Douglas Phase B Estimates.

MCAC Estimate in 1970 \$ 24 M

RI Estimate in 1970 \$ 81 M

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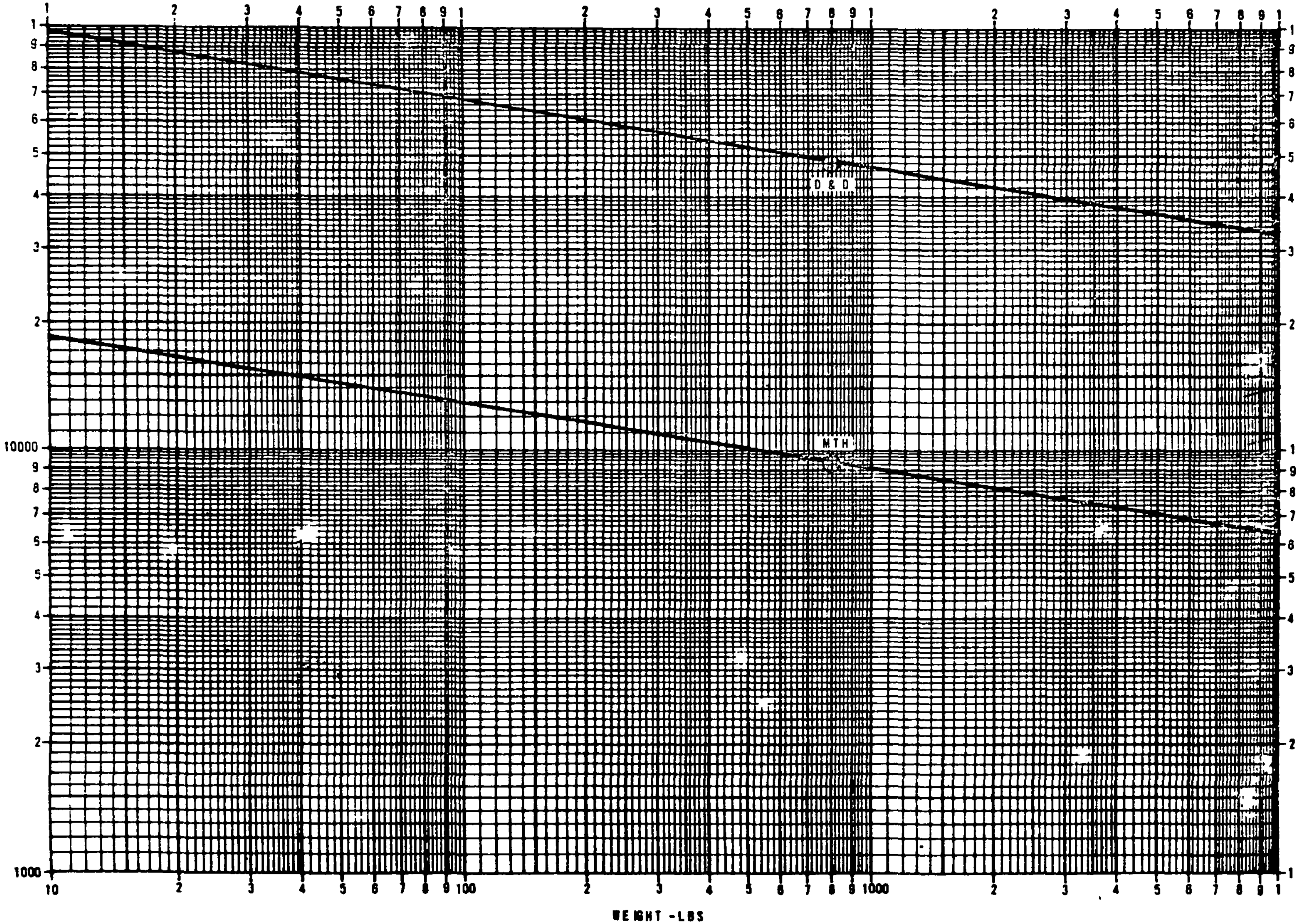
FIGURE X-D-15
REACTION CONTROL SYSTEM
DDT & E COST 1970 $



As mentioned the weight scaling factor between the Phase B station and the SCB is 2.9. Using this factor and the square root relationship used earlier the following costs can be derived.

$(2.9)^{.5}$ X 24 M = \$41 M in 1970 \$, or \$73 M in 1977 \$ based upon

The MDAC Phase B estimate

$(2.9)^{.5}$ X 81 M = \$138 M in 1970 \$, or \$234 M in 1977 \$ based upon

The Rockwell Phase B estimate

Approach 4 - NASA In-house RCS CER (figure X-D-16)

9700 \$/lb is indicated for the 9715 lb RCS using the LM line, while

15,000 \$/lb is indicated by the CSM line.

9715 lbs X 9700 \$/lb = 94 M in 1970 \$, or \$169 M in 1977 \$

9715 lbs X 15000 \$/lb = 146 M in 1970 \$, or \$262 M in 1977 \$

<u>Range of Estimates</u>

Rockwell CER	740 M
Gemini Scaling	177 M
Apollo Block 1 Scaling	750 M
MDAC Phase B Scaling	73 M
Rockwell Phase B Scaling	134 M
NASA In-House CER - Upper Limit	262 M
NASA In-House CER - Lower Limit	169 M

Estimate Selected - \$250 M

<u>Theoretical First Unit Cost</u>

Appr oach 1 - The Rockwell CER (figure X-D-17) indicates thate the First RCS unit should cost approximately 3200 \$/lb.

9715 lbs X 3200 \$/lb = \$31 M in 1970 \$, or \$56 M in 1977 \$

Approach 2 - The NASA CER (figure X-D-18) indicates that if the RCS is of similar complexity as the RCS of the program represented by the lower line it should cost 3600 \$/lb; or 35 M in 1970 \$, \$62 M in 1977 \$. If it is similar in complexity to the program represented by the upper line it should cost approximately 5200 \$/lb; or \$50 M in 1970 \$, \$90 M in 1977 \$.

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FIGURE X#D-16

REACTION CONTROL SYSTEM

DDT&E COST

1970 COST

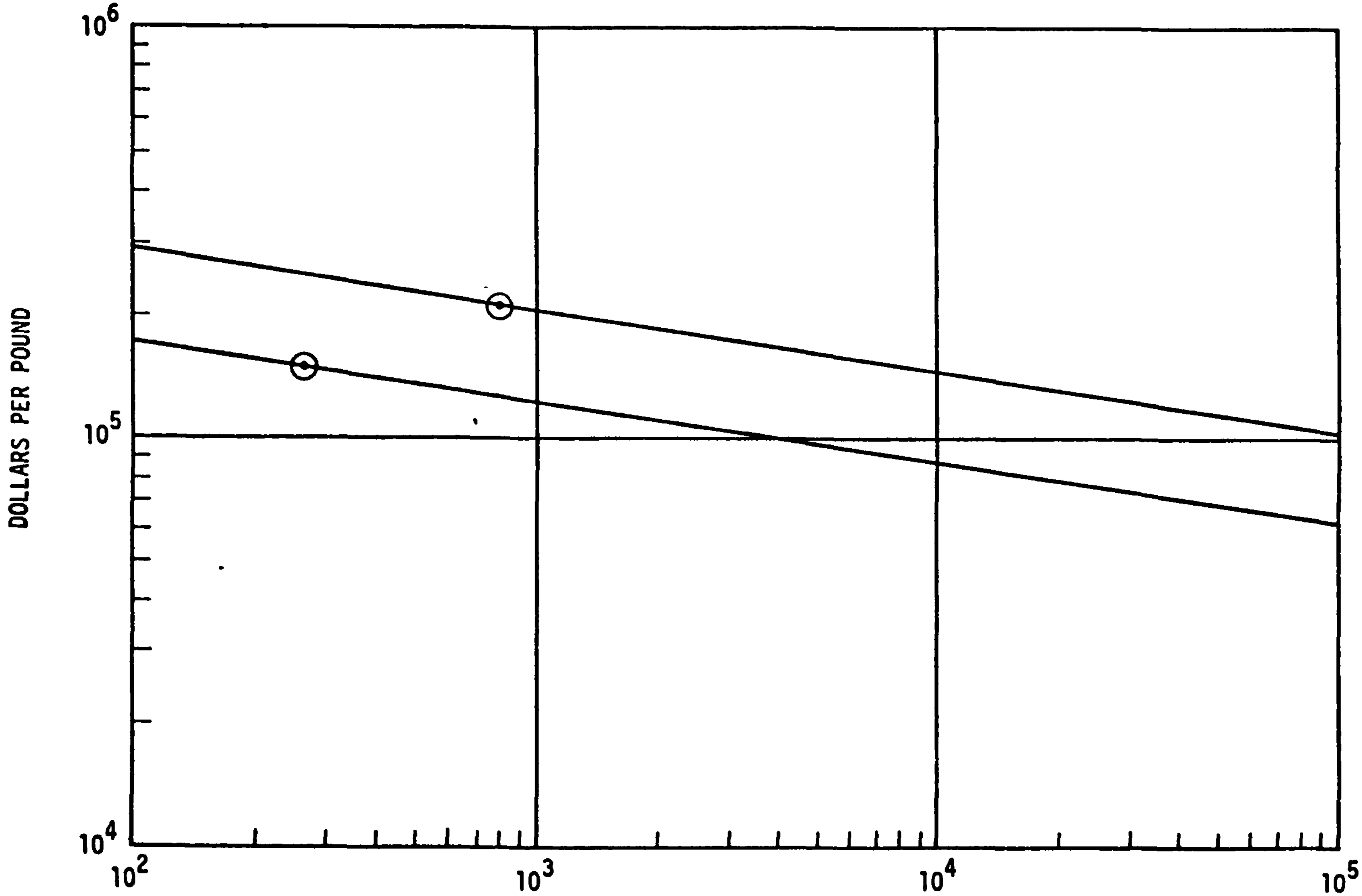

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FIGURE X-D-17
REACTION CONTROL SYSTEM
TFU COST 1970 $

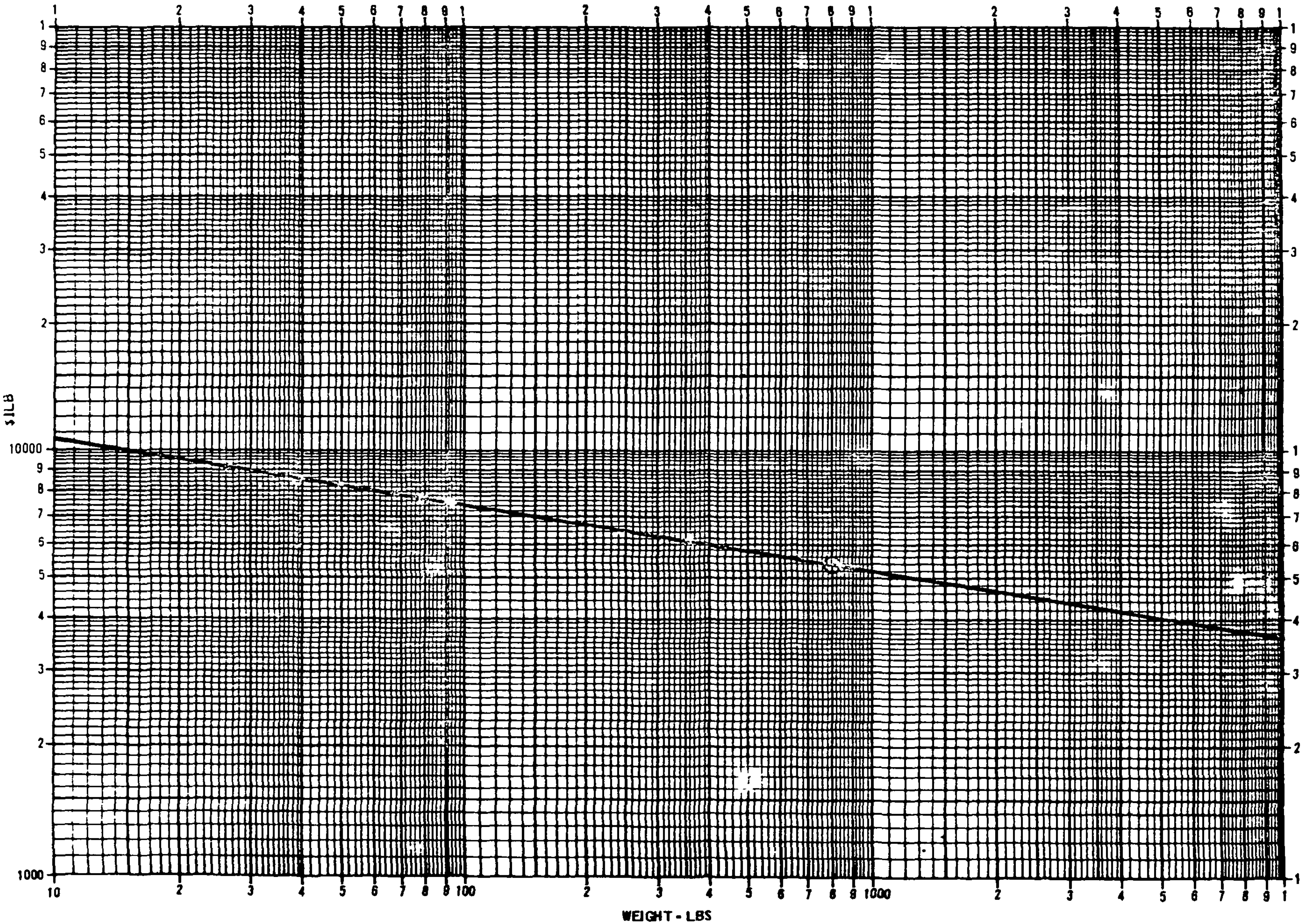

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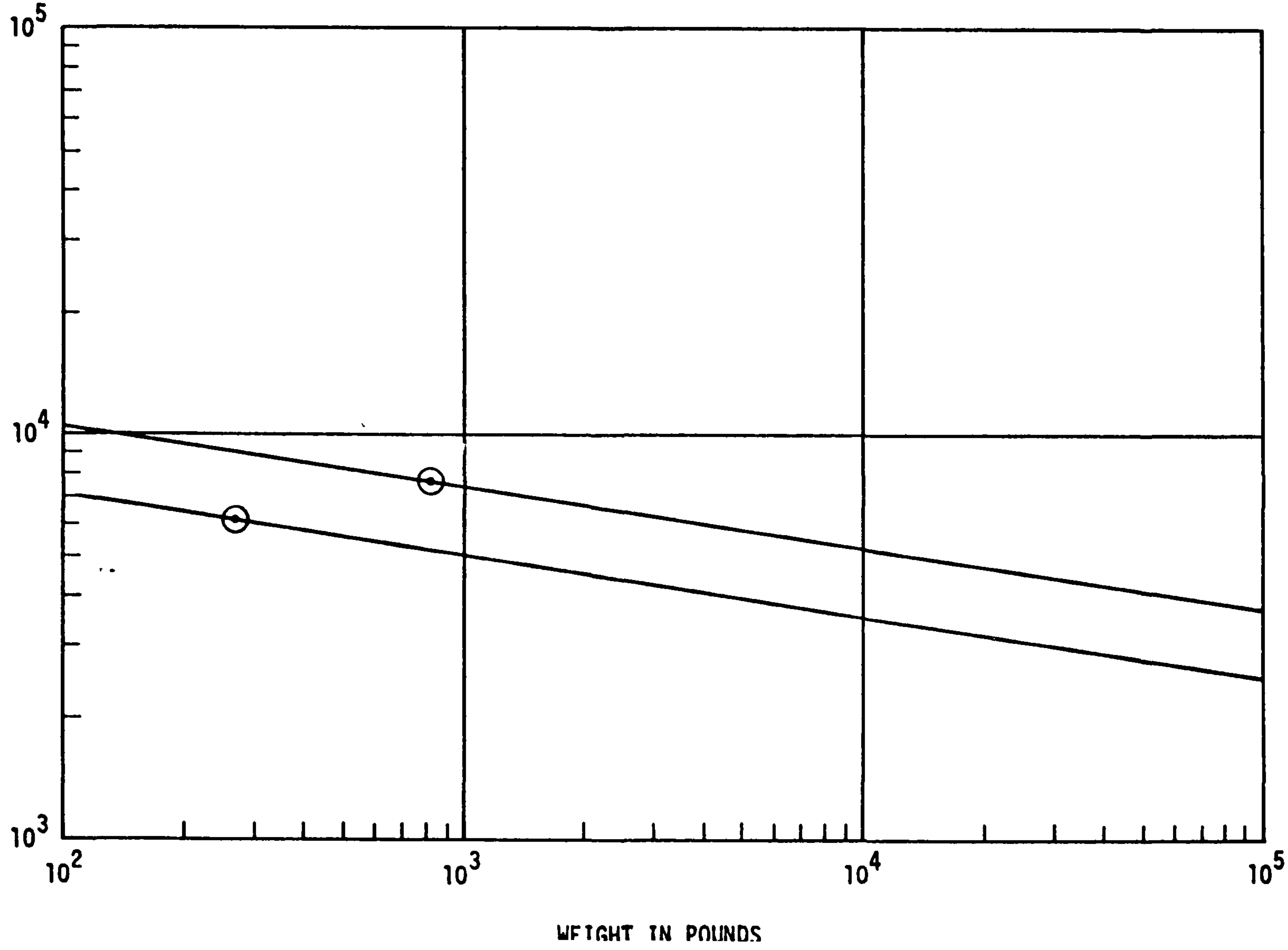
FIGURE X-D-18

REACTION CONTROL SYSTEM

TFU COST

1970 $



Approach 3 - Extrapolation/Scaling of the Rockwell and McDonnell-Douglas Phase B Data results in the following estimates.

1. $(2.9)^{0.75}$ X \$18.2 M = \$40 M in 1970 \$ or \$73 M in 1977 \$, based upon the Rockwell Phase B estimate.

2. $(2.9)^{0.75}$ X \$7 M = \$15 M in 1970 \$, or \$28 M in 1977 \$, based upon the MDAC Phase B estimate.

Range of estimates:

Rockwell CER	\$56 M
NASA CER - LM complexity	\$62 M
NASA CER - CSM complexity	\$90 M
Rockwell Phase B Scaling	\$73 M
MDAC Phase B Scaling	\$28 M

Estimate Selected - \$70 M

1.3.1.1.4 Environmental Protection

DDT&E

Approach 1 - Based upon a weight of 27, 666, and by using the Rockwell CER in figure X-D-19, an estimate for DDT&E in 1970 \$ as follows can be derived.

\$940/lb X 27,666 = \$26 M for Major Test Hardware

\$2200/lb X 27,666 = \$61 M for Design & Development
\$87 M in 1970 \$

This escalates to \$156 M in 1977 \$

Approach 2 - Scaling/Extrapolation of Rockwell Phase B Estimates

Rockwell estimate - \$36.9 M in 1970 \$

$(2.9)^{0.5}$ X 36.9 M: \$63 M in 1970 \$, or \$107 M in 1977 \$

The work breakdown structure (WBS) used by MDAC in Phase B allocated ECLSS, crew habitability and environmental protection in such a way that it would have been difficult to cleanly extract cost estimates for environmental protection.

Range of Estimates:

Rockwell CER	\$156 M
Rockwell Phase B Scaling	\$107 M

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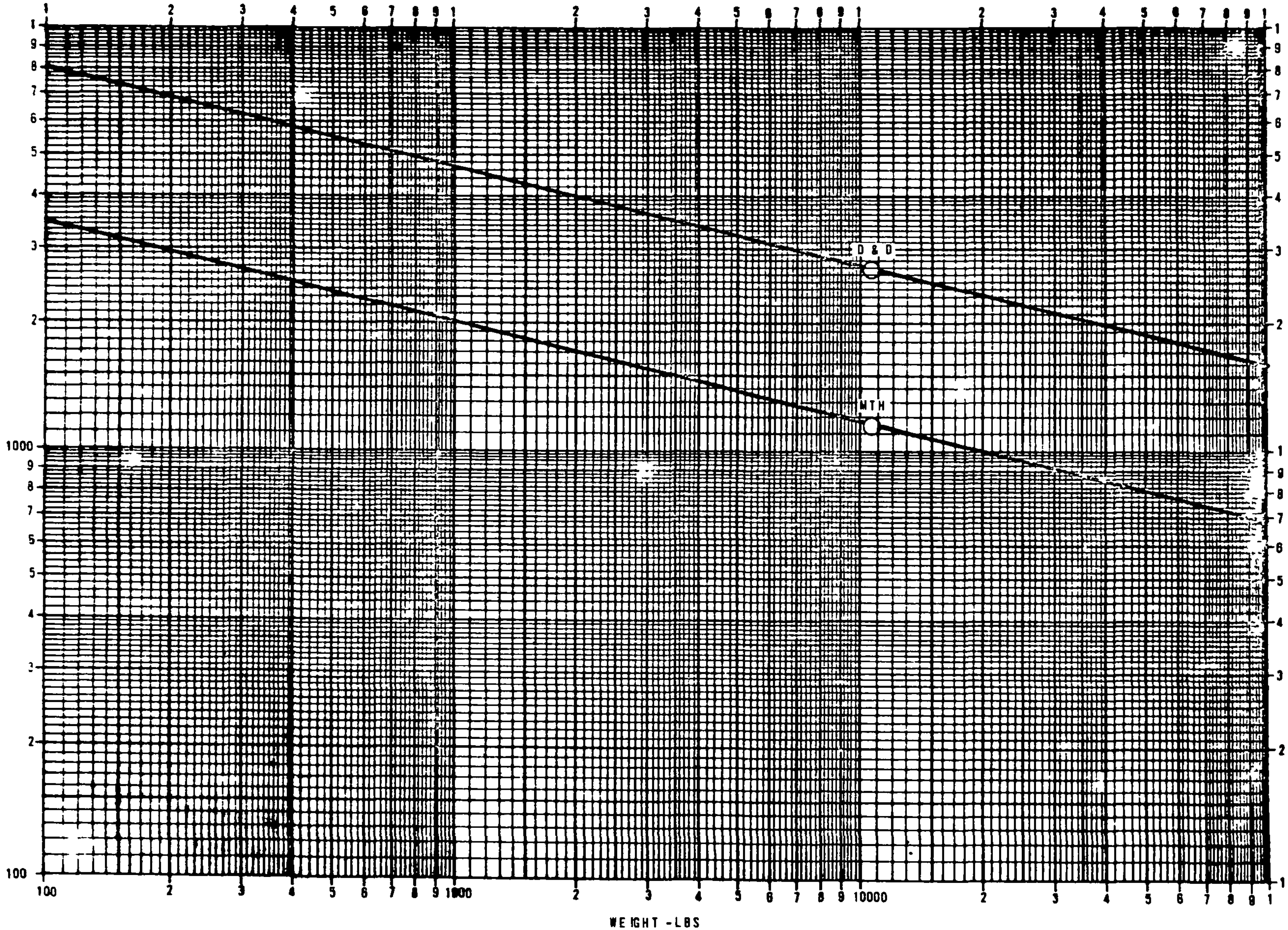
FIGURE X-D-19
ENVIRONMENTAL PROTECTION SYSTEM
DDT & E COST 1970 $



Estimate Chosen - $150 M

Theoretical First Unit

Approach 1 - An estimate of $50 M in 1977 $ results from using the Rockwell CER (figure

$1000/lb X 27,666 lbs = $28 M in 1970 $, or $50 M in 1977 $

Approach 2 - Scaling of Rockwell Phase B data results in the following estimate:

$(2.9)^{0.75}$ X the Rockwell Phase B estimate of $16.3 M equals $36 M in 1970 $, or $62 M in 1977 $.

Range of Estimates:

Rockwell CER	$50 M
Rockwell Phase B Scaling	$62 M

Estimate Chosen - $50 M

1.3.1.1.5 Tooling

DDT&E

Approach - The CER which forms figure X-D-21 is the standard tool used by JSC in estimating the cost of tooling. The lower line represents the CER to be used when estimating tooling used for aluminum skin and stringer structures. A structure of this sort weighing approximately 104,000 lbs, the derived weight for the structure, would have a DDT&E cost of approximately $85 M in 1970 $ or $153 in FY 1977 $. No complexity factor was applied. In the judgement of the estimator the relative complexity of 1.3 applied to the structure CER does not apply since the primary structure material and total structure weight drive the tooling cost, rather than secondary structure complexity.

The DDT&E estimate chosen was $150 M.

Production - The Apollo factor of 3.6% of hardware TFU cost results in an estimate of $20 M.

1.3.1.1.6 Stabilization/Guidance & Control

DDT&E

Approach 1 - The Rockwell CER in figure X-D-22 was used to estimate the cost of the S&C system for the Space Construction Base. While the total system weights 5,046 lbs., only 1934 will be new development according to the Rockwell Phase B assumptions. The following table breaks the total weight between that which is new development, and common weight which is composed of articles identical to those developed as "new weight."

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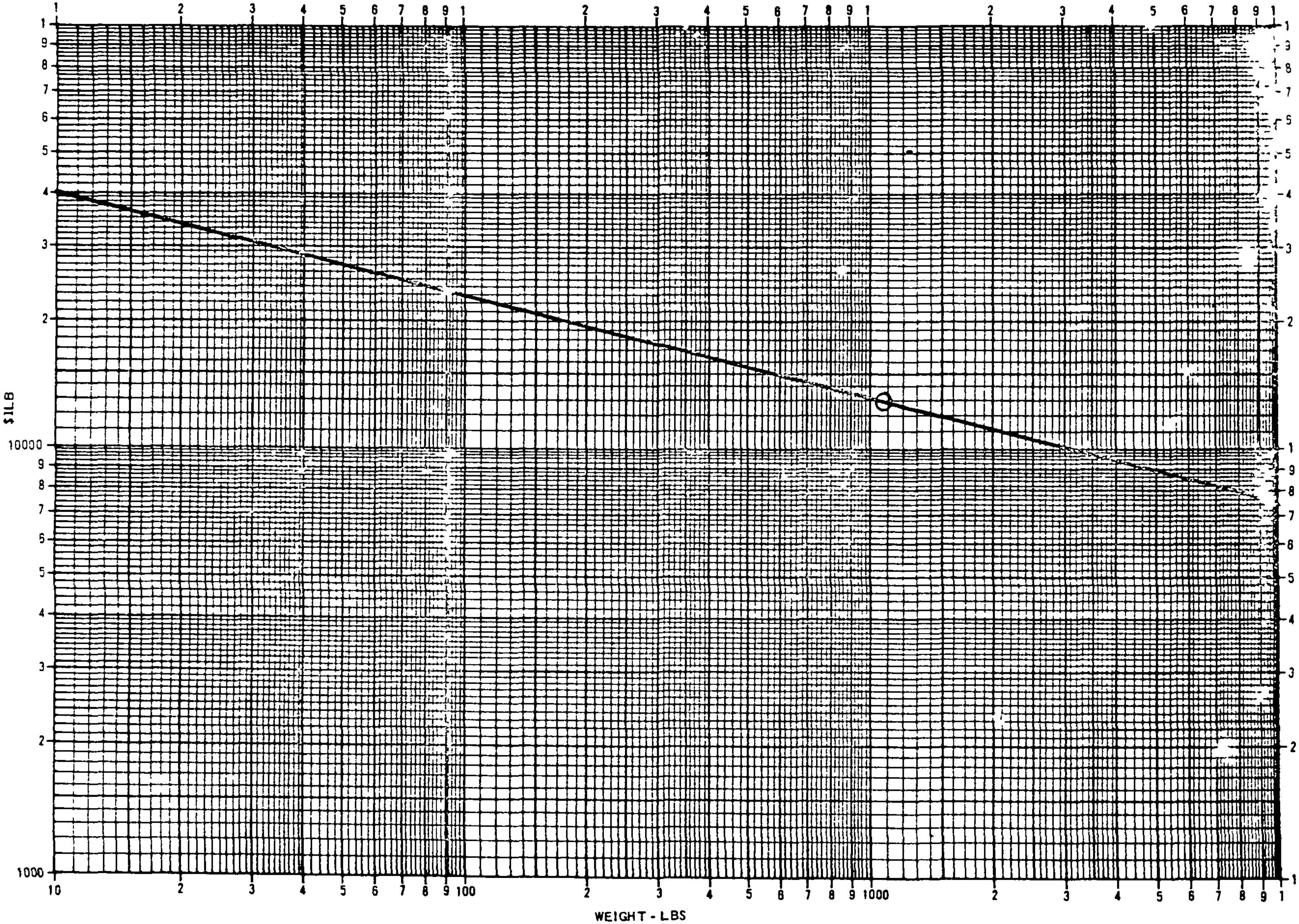
FIGURE X-D-20
ENVIRONMENTAL PROTECTION SYSTEM
TFU COST 1970 $



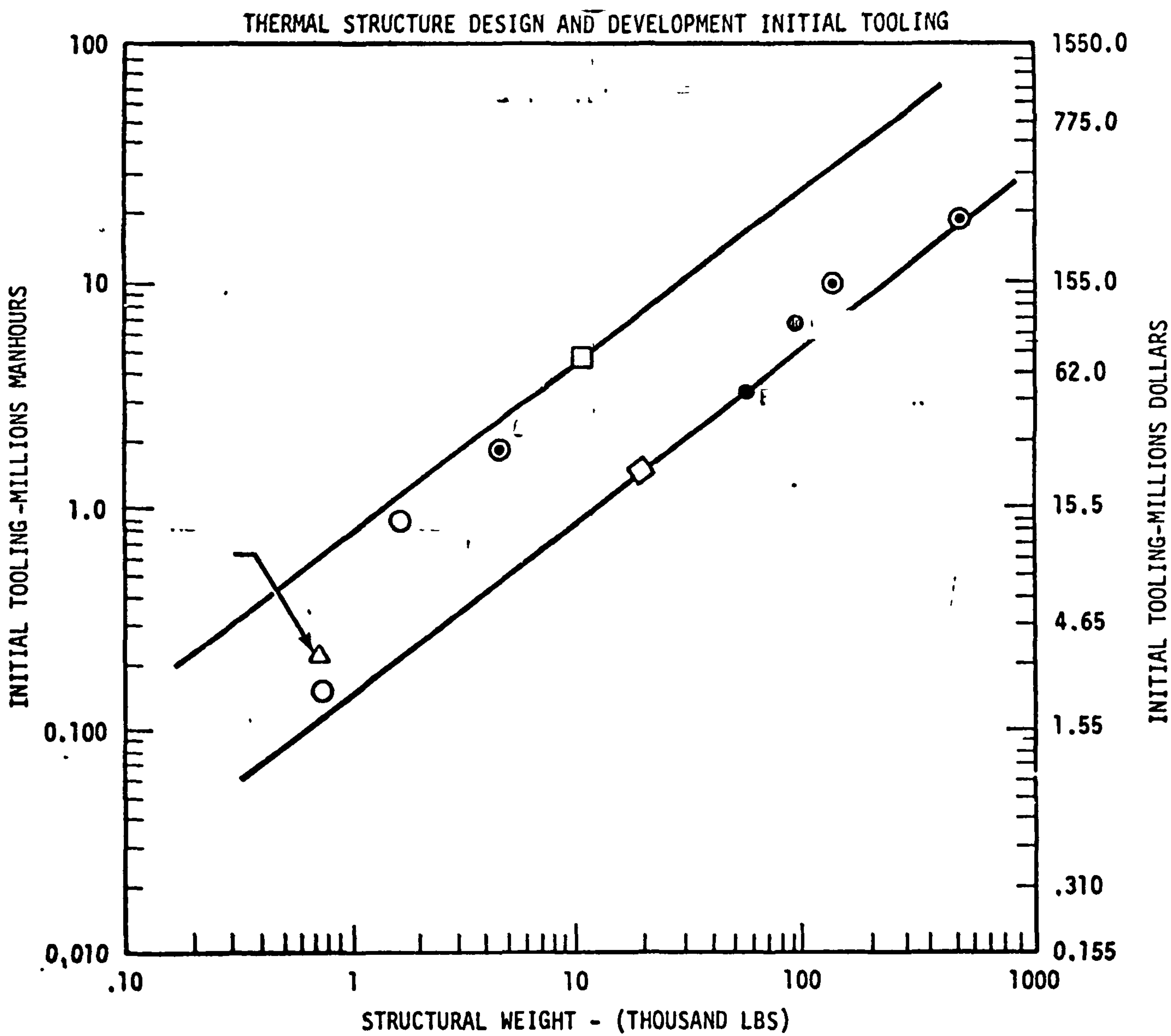


FIGURE X-D-21 THERMAL STRUCTURE DESIGN AND DEVELOPMENT INITIAL TOOLING

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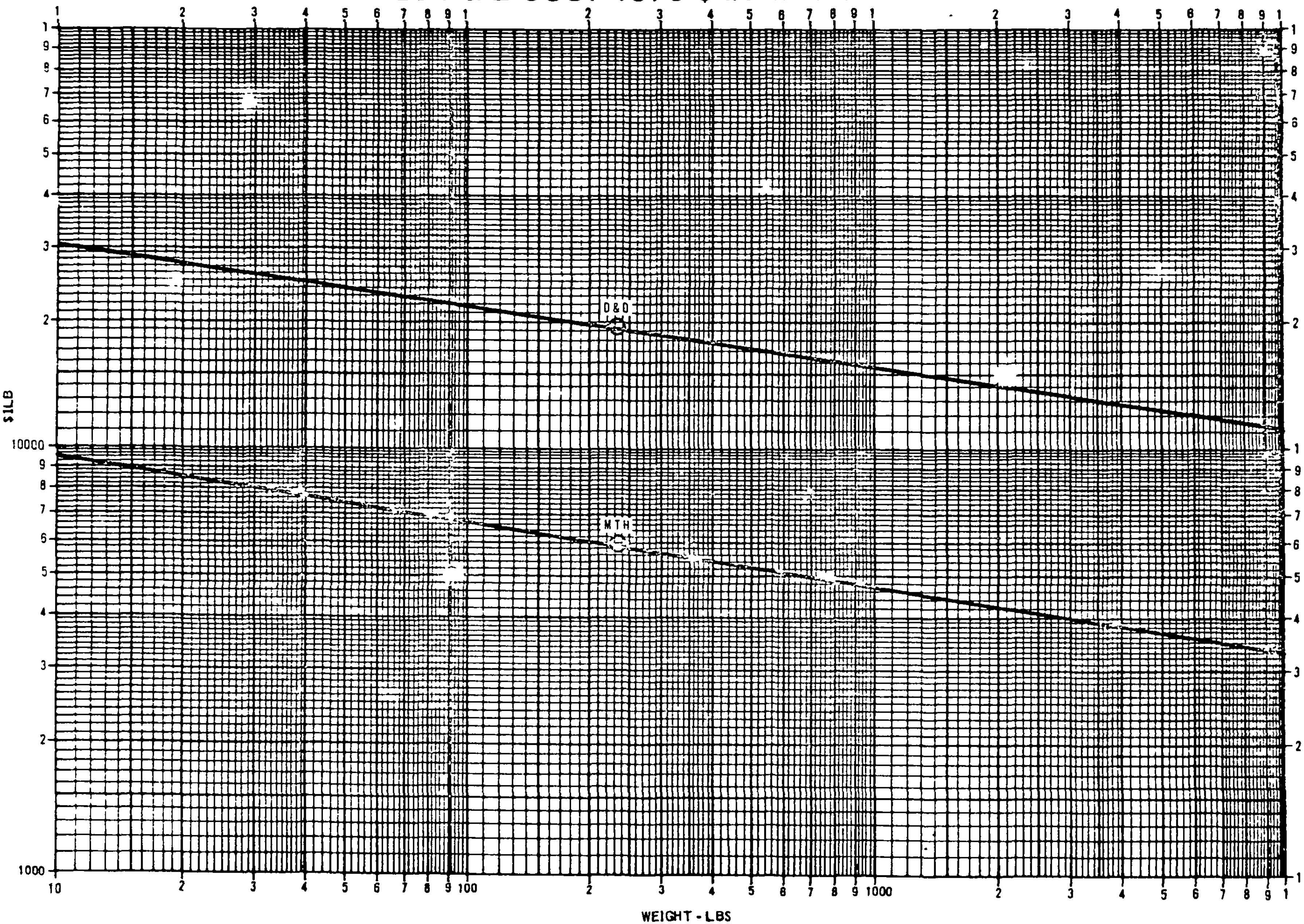
FIGURE X-D-22
STABILIZATION & CONTROL SYSTEM
DDT & E COST 1970 $ IN MILLIONS



Element	Total Weight	New Weight	Common Weight
Inertial Reference System	235	116	119
Optical Reference	989	493	496
Control Moment Gyros	3515	1171	2343
RCS Electronics	307	154	154
	5046	1934	3112

The new weight figure of 1934 lbs was used to estimate the cost of design and development (D&D) while the total weight of 5046 was used to estimate the cost of Major Test Hardware.

For D&D

1934 lbs X \$140,000/lb = \$271 M in 1970 \$, or \$486 M in 1977 \$

For MTH

5046 lbs X \$37,000/lb = \$187 M in 1970 \$, or \$335 M in 1977 \$

\$486 M + \$335 M = \$821 M for total S & C

Approach 2 - Scaling of Rockwell and McDonnell-Douglas Phase B cost data.

$(2.9)^{0.5}$ X \$183 M = \$311 M in 1970 \$, or \$559 M in 1977 \$ based upon the Rockwell Phase B estimate.

$(2.9)^{0.5}$ X \$56 M = \$92 M in 1977 \$, or \$171 M in 1977 \$, based upon the MDAC Phase B estimates.

Range of Estimates:

Rockwell CER	\$821 M
Scaling of Rockwell Phase B Estimate	\$559 M
Scaling of MDAC Phase B Estimate	\$171 M

Estimate Chosen - \$350 M

Theoretical First Unit Cost

Approach 1 - By use of the Rockwell CER which forms figure X-D-23, it can be determined that the TFU cost for a S & C system weighing 5046 lbs would cost $14,000/lbs in 1970 $, or $71 M. In 1977 $ this equals $127 M.

Approach 2 - Figure X-D-24 is a JSC CER for TFU for Guidance and Control (G&C) subsystems. The following estimates can be derived in 1977 $ by use of this CER.

Low Complexity	43 M
Medium Complexity	181 M
High Complexity	426 M

Approach 3 - Scaling of RI MDAC Phase B Cost Estimates.

(2.9) 0.75 X 28 = $62 M in 1970 $, or $112 M in 1977 $ based upon the RI Phase B estimate

(2.9) 0.75 X 10 = $22 M in 1970 $, or $40 M in 1977 $ based upon the MDAC Phase B estimates.

Range of Data

Rockwell CER	$127 M
JSC CER	
- Low Complexity	$ 43 M
- Medium Complexity	$181 M
- High Complexity	$426 M

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FIGURE X-D-23
STABILIZATION AND CONTROL SYSTEM
TFV COST 1970 $

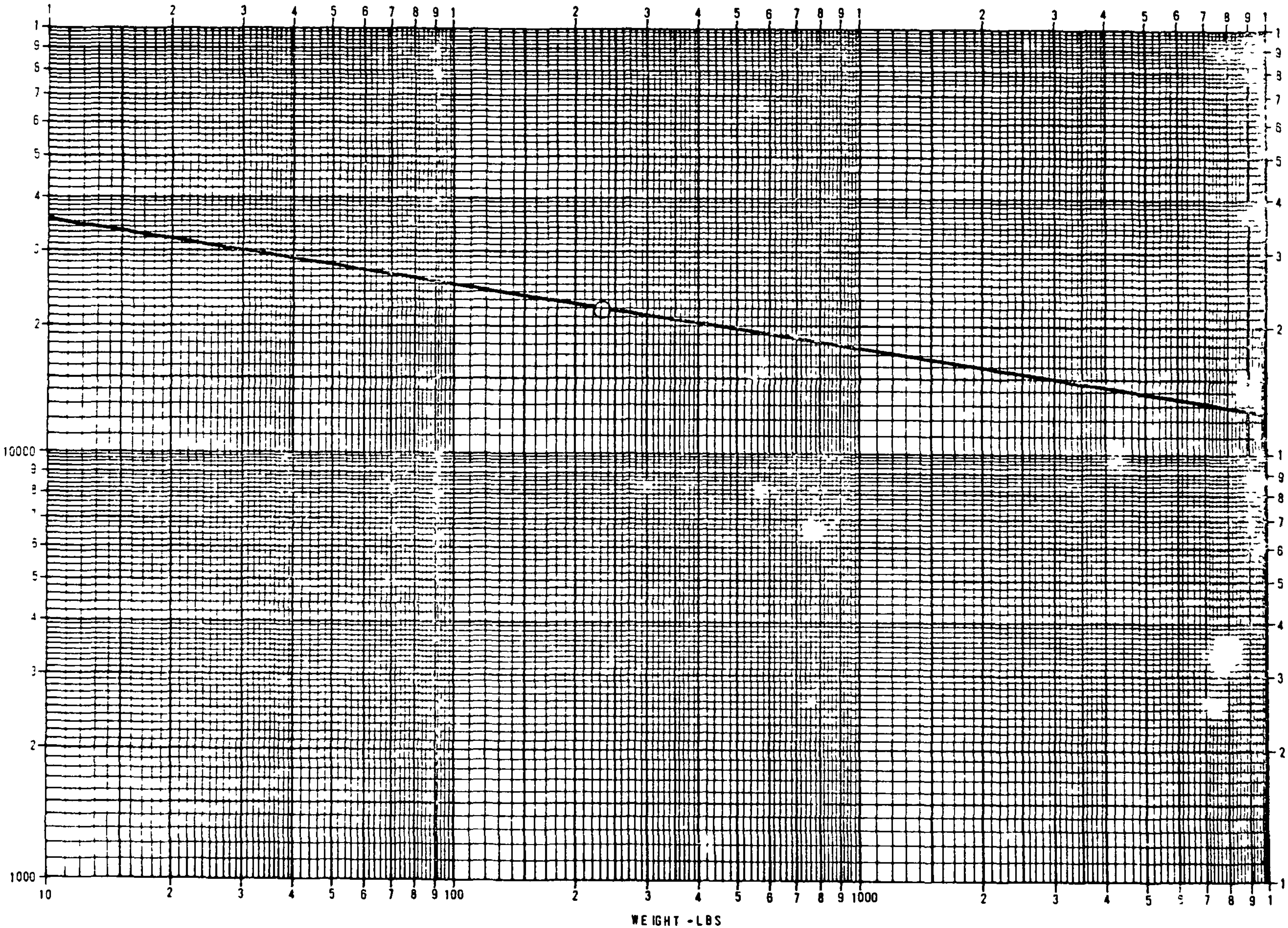

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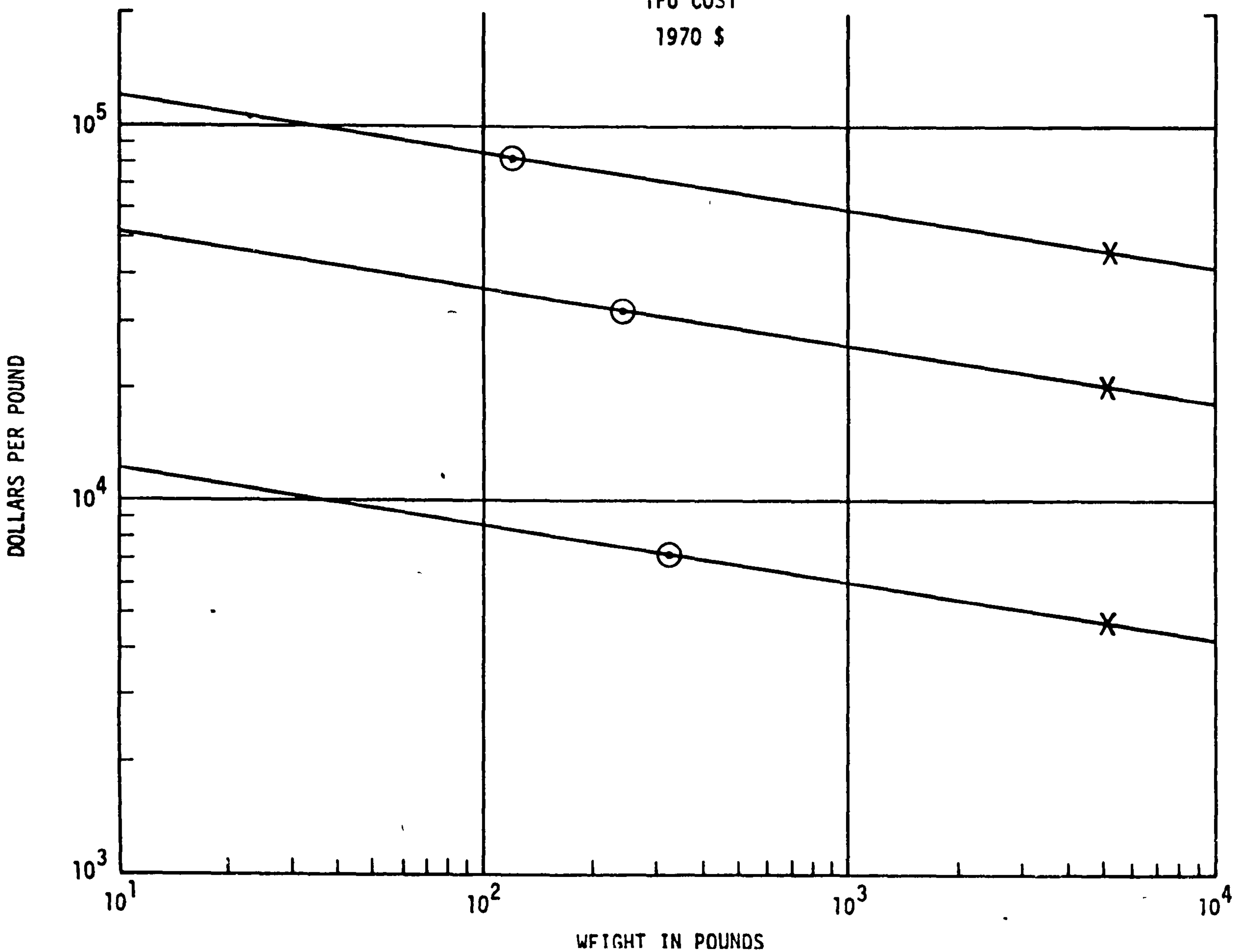
FIGURE X-D-24

GUIDANCE AND CONTROL SYSTEM

TFU COST

1970 $



- Scaling of RI Phase B Estimate $112 M
- Scaling of MDAC Phase B Estimate $ 40 M

Estimate Chosen - $100 M

1.3.1.1.7 Instrumentation/Communications/Data Management

DDT&E

Approach 1 - Figure X-D-25, the CER for communications system was used to estimate the cost of the WBS element "Communications." The $100 M line was used since the integration of the communications systems for 28 modules, EVA operations, etc., will be complex. An estimate of $111 M in 1970 $ was developed using the CER. This escalates to $199 M in 1977 $.

A number of $105 M in 1977 $ can be estimated for Instrumentation (including data processing and controls/displays) by use of figure X-D-26. In 1977 $ this equals $189.

Software was estimated at 15% of hardware cost. 0.15 (189 + 199) = $446 M.

Approach 2 - Scaling of Rockwell and MDAC Phase B Data.

$(2.9)^{0.5}$ X 260 = $442 M in 1970 $, or $793 M in 1977 $, based upon the Rockwell Phase B estimate.

$(2.9)^{0.5}$ X 146 = $248 M in 1970 $, or $446 M in 1977 $, based upon the MDAC Phase B estimates.

Range of Data:

JSC CER	$446 M
Scaling of Rockwell Phase B Cost	$793 M
Scaling of MDAC Phase B Cost	$446 M

Estimate Chosen - $450 M

Theoretical First Unit (TFU)

Approach 1 - Figures X-D-27 and 28 indicate costs as follows:

	1970 $	1977 $
Communications	11 M	20
Instrumentation	10 M	18
Software at 15%	3 M	5
Total	24 M	43 M

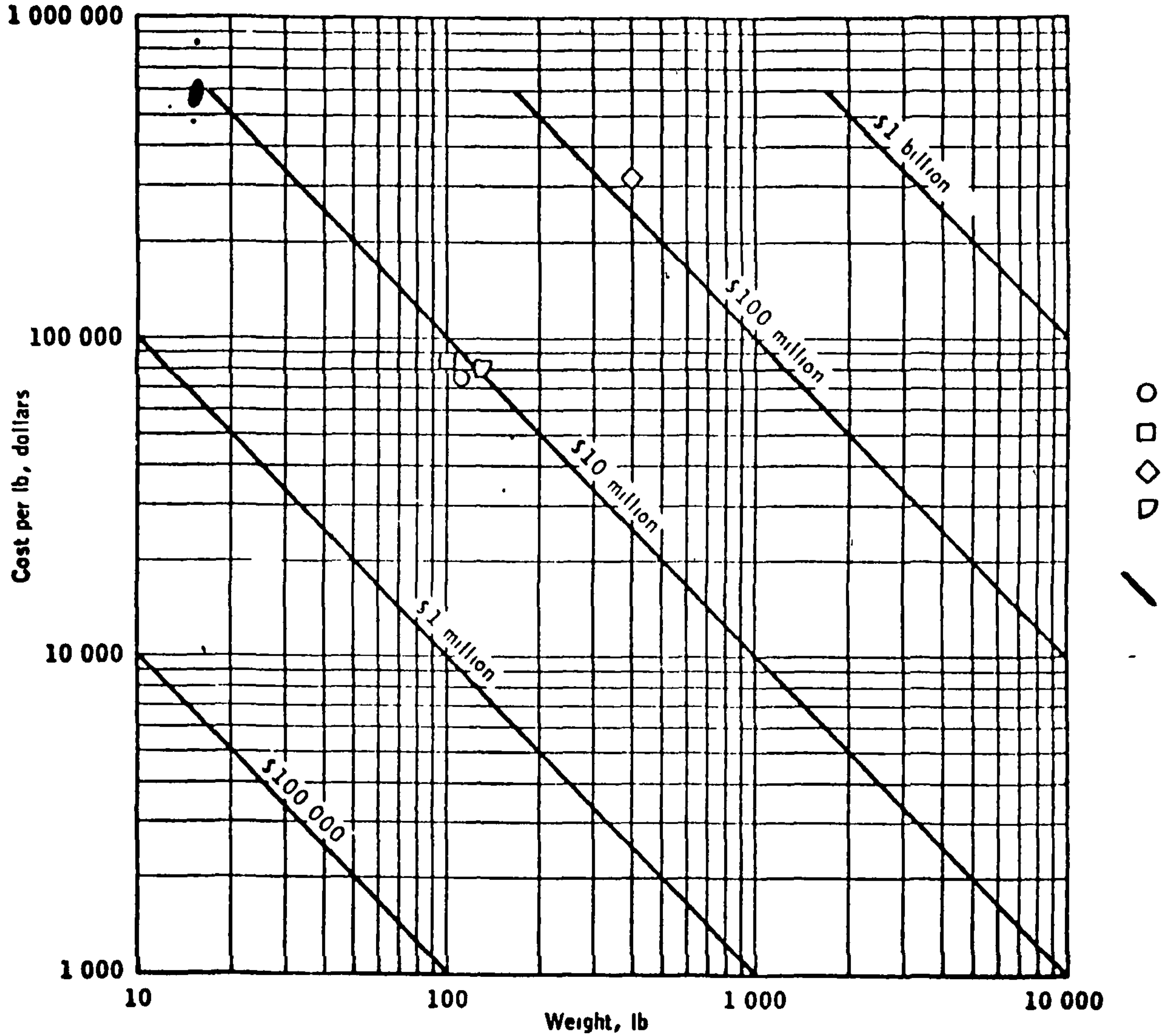


FIGURE X-D-25. - **Communications nonrecurring costs.**

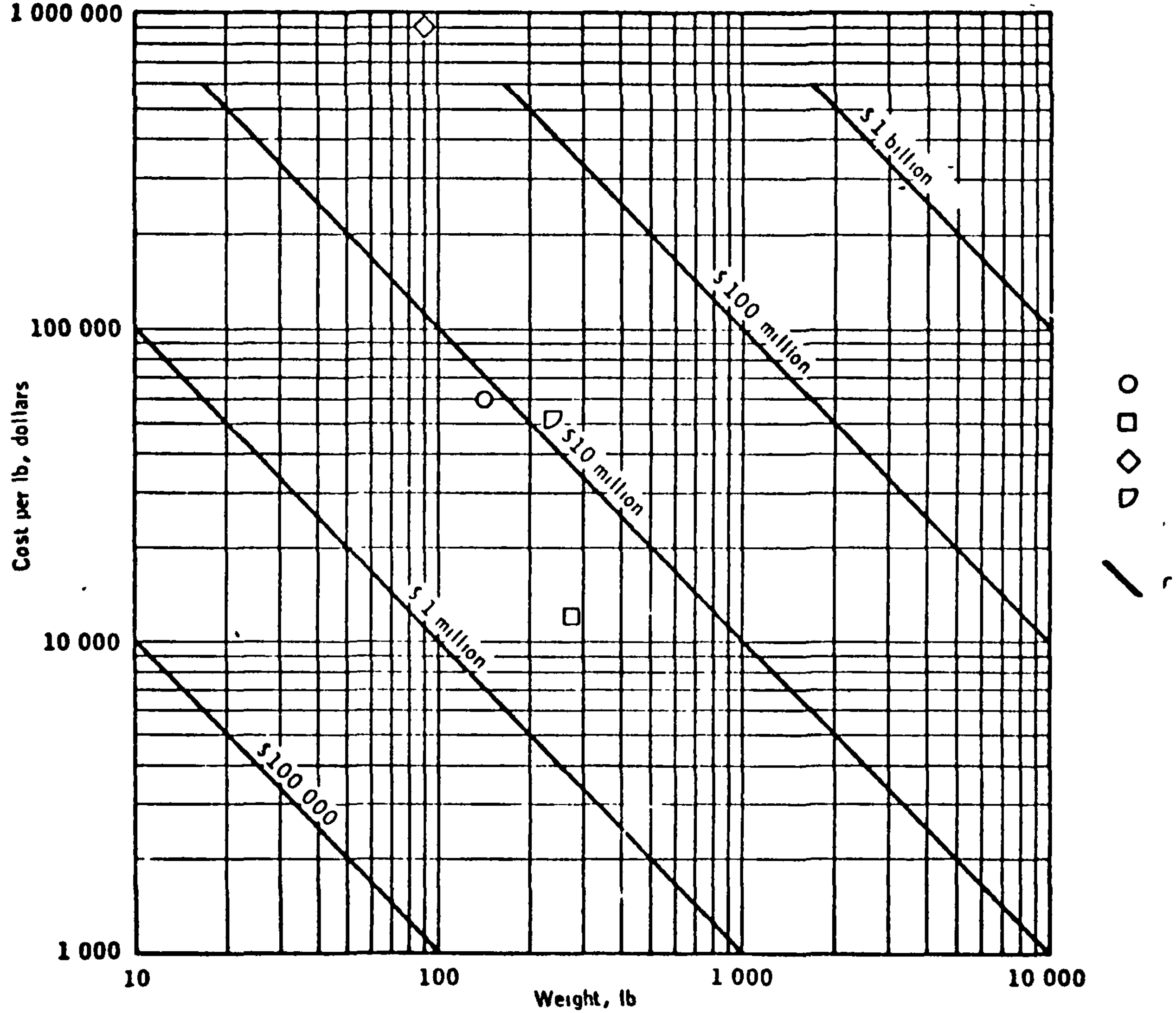


FIGURE X-D-26. - **Instrumentation nonrecurring costs.**

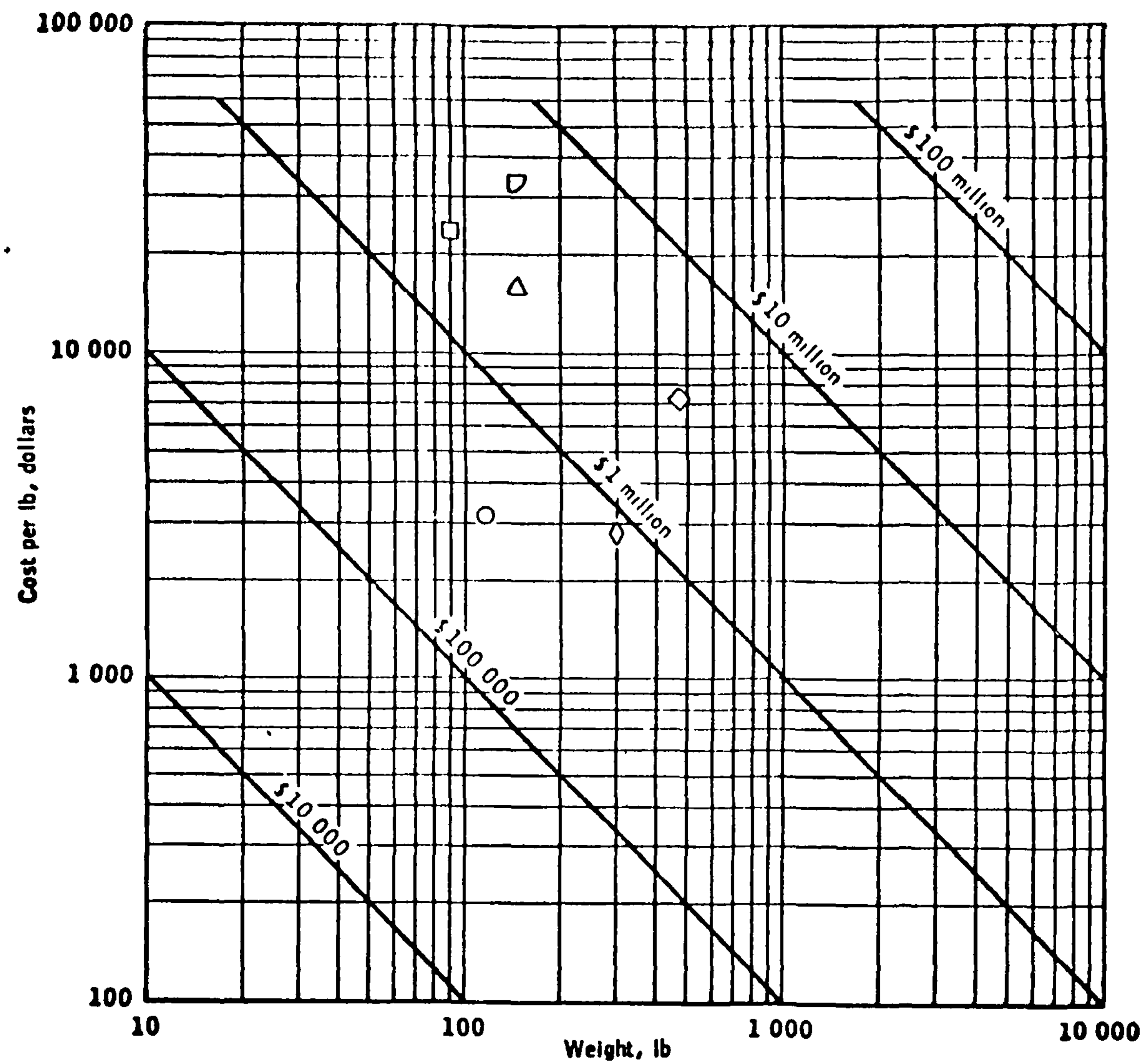


FIGURE X-D-27 - **Communications first-item costs.**

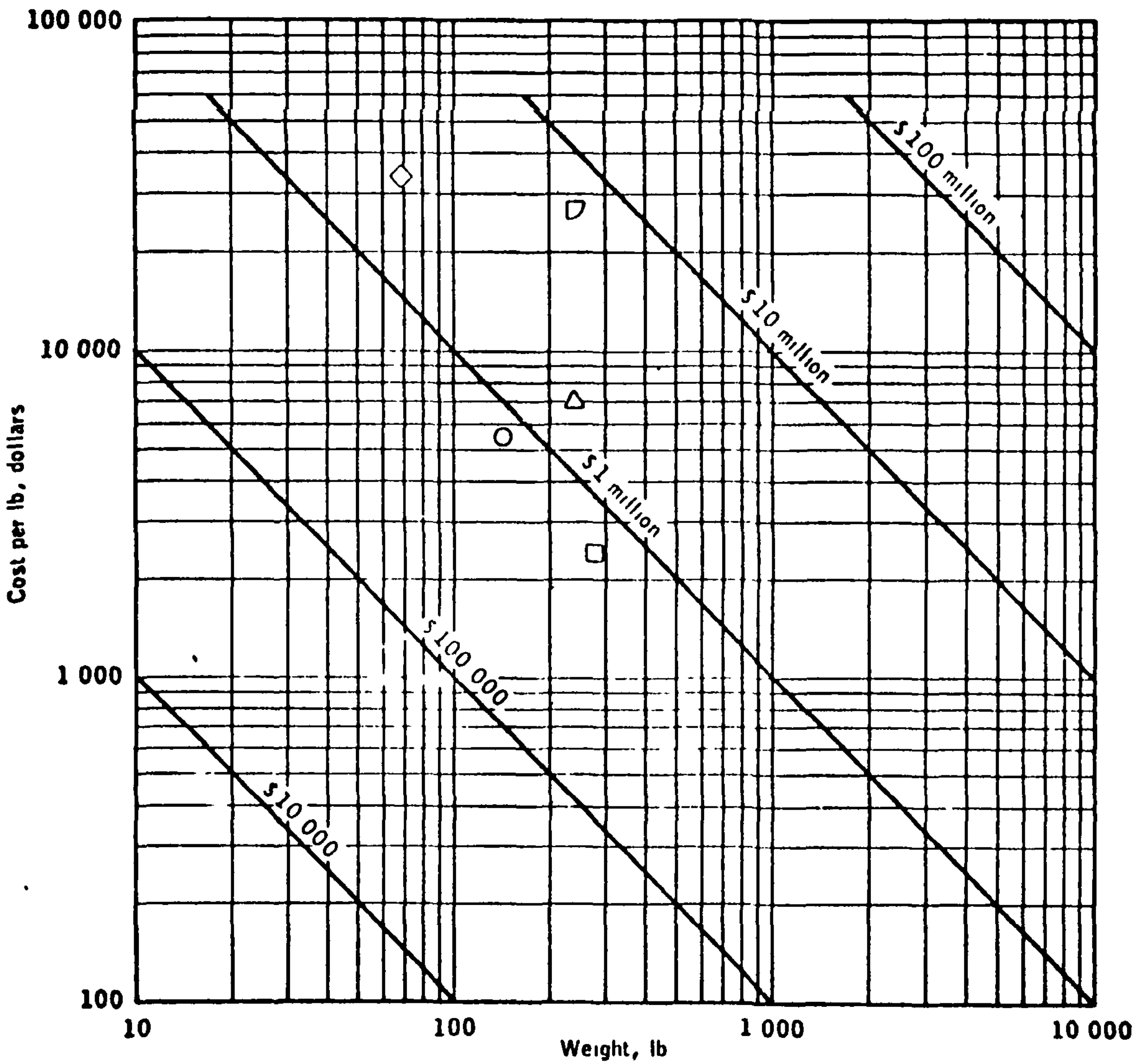


FIGURE X-D-28 - **Instrumentation first-item costs.**

Approach 2 - Scaling of Rockwell & MDAC Phase B Cost Data

$(2.9)^{0.75}$ X \$96.3 M = \$214 in 1970 \$, or \$348 M in 1977 \$ based upon the Rockwell Phase B Estimate.

$(2.9)^{0.75}$ X \$18 M = \$40 M in 1970 \$, \$72 M in 1977 \$ based upon the MDAC Phase B Estimate.

Range of Data:

JSC CER	\$43 M
Scaling of Rockwell Phase B Data	\$384 M
Scaling of MDAC Phase B Data	\$ 72 M

Estimate Chosen - \$50 M. Discussions with JSC and contractor personnel indicate a general feeling that \$50 M is very adequate for the first unit cost (including all DDT&E) for communications, instrumentation, data processing and display and controls equipment. The range of the data would indicate a higher number.

1.3.1.1.8 Electrical Power System

DDT&E

Approach 1 - No CER could be located which could be used to estimate the cost of a 74,197 EPS using solar arrays, consequently the assembly-level Rockwell Phase B were scaled to scope the cost of a solar array EPS using 1970 technology.

Element	WT	Data Source	Cost (1977 \$ M)
Solar Array	13688	GE Cost Data	121
Orientation System	829	Apollo EPS	18
Mounts & Supports	7059	S-II Structure	36
Fuel Cells	1392	Apollo Pratt & Whitney	90
Plumbing	464	Beech Aircraft Cryo Tank	22
Batteries	33147	Apollo Eagle Picher Battery	42
Equipment & Controls	5258	Apollo EPS CER	102
Distribution & Wiring	12360	Apollo EPS CER	48
TOTAL	74197		480

Approach 2 - Discussions with JSC and contractor personnel indicate that a realistic estimate for a 300-500 KW solar array system for the SCB in the 1985-1995 timeframe would be $100 M in 1977 $, $64 M of which would be DDT&E. This estimate includes all equipment up to the distribution and wiring interface.

To this add $48 M for distribution and wiring, $10 M for design mods to the Shuttle Fuel cells, $102 M for equipment and controls, and $24 M for batteries. Discussions with JSC and contractor personnel led to the lower battery estimate since a larger quantity in lieu of a larger dimension battery could be used.

Summation of the above number results in the following estimate:

Solar Array	$64 M
Distribution and Wiring	$48 M
APU Design Mods	$10 M
Equipment and Controls	$102 M
Batteries	$23 M
Total	$247 M

Range of Data:

Scaled Rockwell Estimate	$480 M
Composite Rockwell/JSC/Contractor	$247 M

Estimate Chosen - $250 M

Theoretical First Unit

The same philosophy applies as in Approach 2 to EPS DDT&E. The $34 M mentioned earlier was assumed to be the TFU cost for the solar array, orientation system and mounts and supports (general structure). To this the following estimates were added:

Solar Array, Orientation, Structure	$34 M
Fuel Cells (Shuttle TFU)	5 M
Batteries (Scaled RI estimate)	16 M
Equipment & Controls (Scaled RI estimate)	12 M
Distribution & Wiring (Scaled RI estimate)	6 M
TOTAL	$73 M

Estimate Chosen - $73 M

1.3.1.1.9 Elevator (for Cargo Module)

The elevator was costed as a large hydraulic system, weighinq 10,000 lbs. The landing gear CER's in figures X-D-29 and 30 were used to cost the elevator. These figures indicate the elevator should cost between \$15 M and \$70 M in 1975 \$. A DDT&E estimate of \$50 M in 1977 \$ was selected. Using the same logic as above the range of TFU estimates would appear to be between \$800 K and \$3 M in 1975 \$. An estimate of \$3 M was used.

1.3.1.1.10 Cargo Transfer System (for Cargo Module)

This system is used to transfer the cargo from the docking module to the storage area. It same rationale was used in 1.3.1.1.9 above and a DDT&E cost of 50 M and TFU cost of \$3 M were selected.

1.3.1.1.11 Cargo Storage Structure (for Cargo Module)

This subsystem consists of approximately 10,000 of structure in and upon which cargo is stored until it is used. By use of figures X-D-8 and 10 the following estimates can be derived in the dollars indicated:

	70 \$	77 \$
DDT&E	27 M	48 M
TFU	4 M	7 M

1.3.1.1.12 Cargo Deployment System (for Cargo Module)

A remote manipulator system of less complexity but greater size than the Shuttle RMS will be used to place materials into work areas from the cargo module. The Shuttle RMS will cost \$75 M in approximately 1977 \$ for DDT&E and will have a unit cost of approximately \$5 M. The above numbers were used for the cargo module.

1.3.1.1.13 EVA Support Station (EVA Storage and Preparation System)

Within this module there will be a station where suits can be recharged, crewmen can sit or recline while preparing for EVA. The most parametric data found was within the Rockwell Phase B WBS element, "Crew Accommodations." By scaling these estimates you arrive at the following numbers:

$(2.9)^{0.5} \times \$19.5\text{ M} = \$33\text{ M}$ in 1970 \$, or \$60 M in 1977 \$ for

DDT&E based upon the Rockwell Phase B estimate for crew accommodations.

$(2.9)^{0.75} \times \$2.6\text{ M} = \$5.8\text{ M}$ in 1970 \$, or \$10 M in 1977 \$

for the TFU of the EVA Support Station based upon the Rockwell Phase B estimate.

FIGURE X-D-29

LANDING GEAR

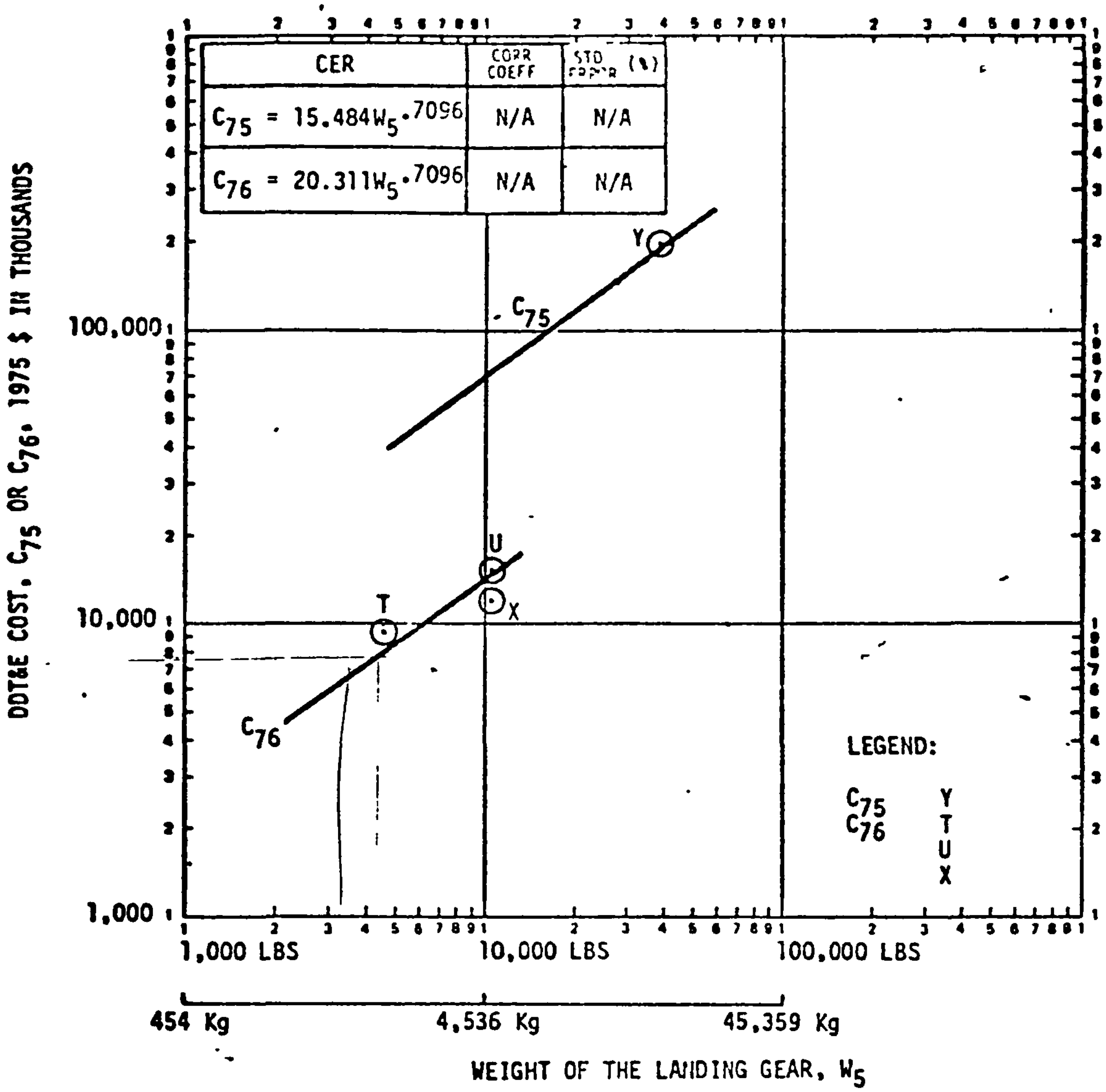
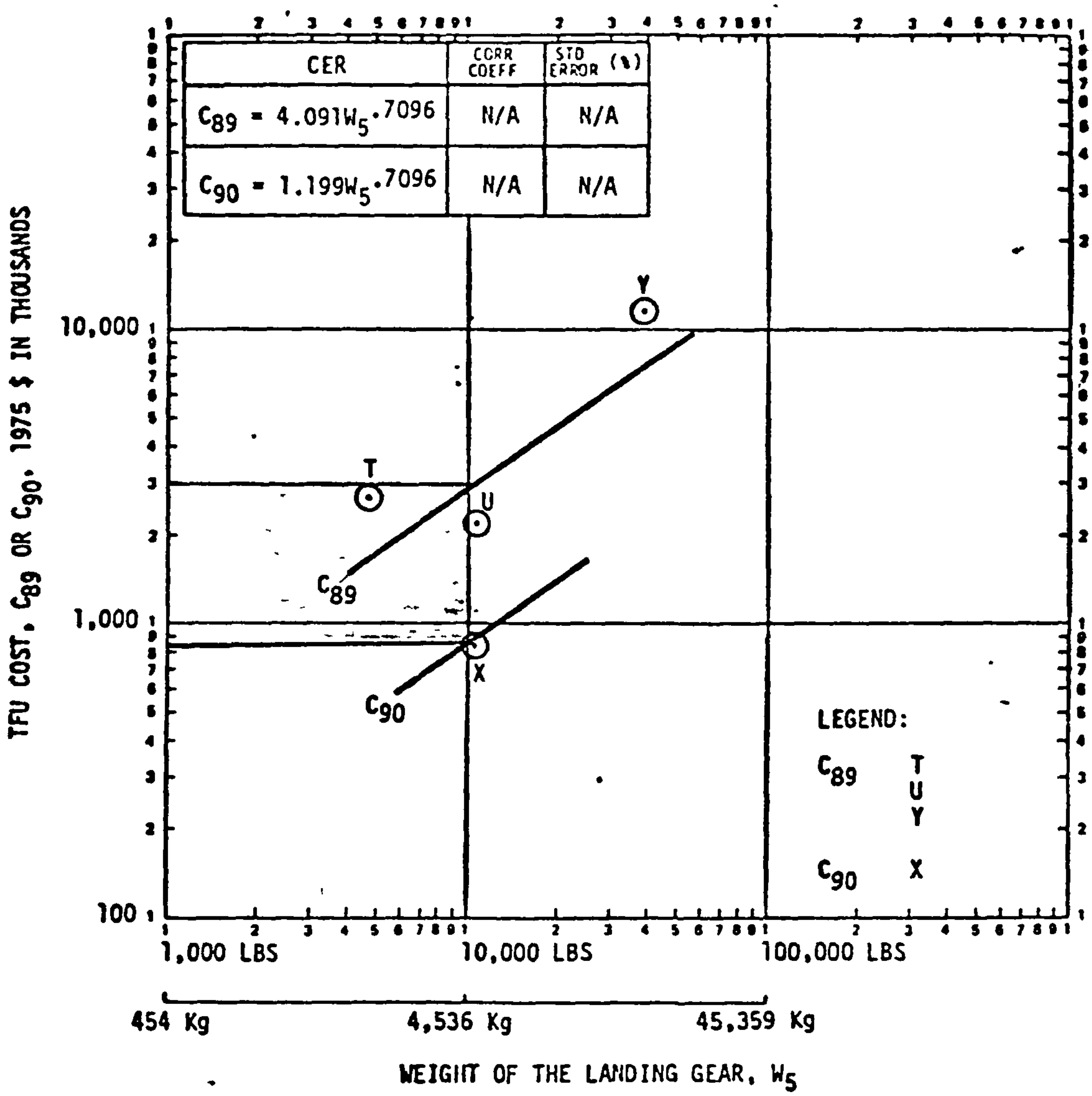


FIGURE X-D-30

LANDING GEAR



1.3.1.1.14 Food Management System (for food galley)

These subsystems, all part of the Galley Module, would include refrigerator/freezers for storage of perishables; a storage area, similar to secondary structure, which would store non-perishables; a food preparation area including sinks and ovens; a cleaning area for wash/dry operations; a general dining area; and a food disposal system. The Rockwell Phase B estimate contained a DDT&E estimate of $36.3 M in 1970 $. By scaling and escalating this number becomes $111 M. No TFU was contained within the above mentioned document. By assuming the same ratio of TFU to DDT&E as in the total ECLS a TFU estimate of $15 M can be developed. There appears to be no duplication of cost between the Food Management system and the ECLSS because the Planning Research Corporation CER used to estimate the cost of the ECLSS did not contain a food management system.

1.3.1.1.15 Physical Fitness System (for Physical Fitness Module)

A separate module for physical fitness might be extravagant, but when compared to a standard National Collegiate Athletic Association Gymnasium, the 196,000 cubic feet in a 50' x 100' module appears reasonable to support a crew of 600. A NCAA gymnasium floor is 94' x 50' within the lines and 114' x 60' including the out of bounds area. All are 18' in height. These dimensions yield a volume of 123, 120 cubic feet for a gymnasium with walls within 10' of the court on the ends and 5' of the court on the sides.

5000 lbs of crew/habitability equipment was used as the standard to cost for the equipment within the physical fitness module. The Rockwell Phase B estimate for 2127 lbs of crew/habitability equipment was $25.6M in 1970 $ for DDT&E and $2.6 M for TFU in 1970 $. Scaling results in the following estimates:

$$\left(\frac{5000}{2127}\ \text{lbs}\right)^{0.5} \times (25.6) = $$ \$39 M in 1970 \$, or \$70 M in 1977 \$ for DDT&E

$$\left(\frac{5000}{2127}\ \text{lbs}\right)^{0.75} \times (2.6) = $$ \$5 M in 1970 \$, or \$9 M in 1977 \$ for TFU

1.31.1.16 Fabrication Assembly System (for Fab and Assemble Module)

Within the two fabrication and assembly modules will be production line equipment which will be used for (1) subarray assembly for the SPS components, (2) production of small components, (3) make-fit work and technical services support, (4) repair of retrieved hardware, etc. The total of all equipment within the fabrication was assumed to be 1.5 as costly in DDT&E and TFU as a beam builder, therefore a DDT&E cost of $300 M and a TFU of $33 M were used. Each Fabricaiton and Assembly Module has a Material Deployment System (MDS) which was assumed to be identical to the cargo deployment module, consequently no DDT&E was assumed.

For simplicity it was assumed that units 1=28 of the MDS were assigned to the Cargo Module and units 29-42 were assigned to the Fabrication and Assembly Module.

1.3.1.1.17 Docking Systems

41 Docking systems, each of which weight 8990 lbs (see Table X-D-14) were assumed to be necessary for each SCB. 25 of these would be required for correction of modules + 16 for docking with the launch vehicles. For costing purposes it was assumed that the docking module was 95% structure and 5% ECLSS. In order to accommodate the electronics and mechanical systems an complexity factor of 1.15 was applied. By use of figures 6 & 8 it can be determined that a structure weighing 8548 lbs would have a DDT&E cost of \$25M in 1970 \$ and a TFU of approximately 3.5M in 1970 \$. In 1977 \$ these equate to \$45M and \$6M respectively.

Using the Planning Research Corporation (PRC) CER's (see figure X-D-12 and 14) the following estimates in 1976 \$ can be derived for the DDT&E of the ECLSS related portion of the Docking System.

$$\text{Design \& Development} = 5.623\ (442\ \text{lbs})^{0.415} = \$12.5\ \text{M}$$

$$\text{Major Test Hardware} = 0.282\ (442\ \text{lbs})^{0.536} = \$26.2\ \text{M}$$

The above total of 38.7 M in 1976 \$ equals \$42 M in 1977 \$. The same ratio of TFU to DDT&E as in the SCB ECLSS was used to determine the TFU of the ECLSS portion of the Docking System.

$$.133 \times 42\ \text{M} = \$6\ \text{M TFU}$$

By adding the above numbers the DDT&E and TFU costs of the docking system bedore adjusting for complexity are \$87 M and \$12 M, respectively. After applying the 1.15 complexity factors mentioned above these become \$100 M and \$14 M.

1.3.1.1.18 Medical Systems (for Clinic Module)

The Clinic Module will provide for emergency treatment for those people who become sich or injured while in space. The assumption must be made that the selection process will eliminate workers with even a reasonable risk of illness while working on the SPS. No biomedical research will be conducted, nor will routine physiological monitoring be planned. It was assumed, based upon scaling from the Rockwell Phase B weight statement, that the Clinic Module would contain 6200 lbs (see crew/habitability weight statement) of beds, chairs, EKG/pulmonary/biochemistry equipment, routine medical equipment, etc. This 6200 lbs was assumed to be 1.5 times as complex as the Rockwell Phase B Crew/Habitability subsystem which consisted of mounts and supports, mobility aids, tethers and restraints, furnishings, medical and dental equipment, and recreational equipment. The 1.5 complexity factor is to accommodate the diagnostic equipment which must be available to support a 600 man work force. Using

the Rockwell Phase B estimates of 21.8 M for DDT&E and $2.0 M for TFU in 1970 $, the following estimates can be developed:

$(2.9)^{0.5} \times 21.8$ = \$37 M in 1970 \$, or \$67 M in 1977 \$ for DDT&E

$(2.9)^{0.75} \times 2$ = \$4 M in 1970 \$, or \$8 M in 1977 \$ for TFU

Application of the 1.5 complexity factor results in the following numbers:

$67 M X 1.5 = $100 M for DDT&E

$8 M X 1.5 = $12 M for TFU

1.3.1.1.19 Simulation Laboratory (for Training and Simulation Module)

It was assumed that two of the three crew simulation and training devices would be used in the SCB as on ground and that 25% of the DDT&E costs discussed in WBS 1.3.1.2.1 would be required to space -rate the simulator equipment.

The small scale mockup of the SGB will not be duplicated in space. The assumption was made that the TFU for the ground unit and SCB unit were the same and production learning began with the second SCB unit.

	DDT&E	TFU
Fabricaiton & Assembly Simulation		
- Ground System	40	16
- SCB System	10	8*
EVA/IVA Part Task Simulator		
- Ground System	11	4
- SCB System	3	4
Total		
- Ground System	41	20
- SCB System	13	12

*The Shuttle Mission Simulator upon which this estimate was based contained an $8 M computer. The assumption was made that the SCB IMS/Comm/Data system could provide this capability.

1.3.1.1.20 Recreational Systems (for Recreational Module)

The recreational module will contain approximately 4000 of crew/habitability type equipment including a movie theather and television room. Reading material will be displayed on consoles. The remainder of the module will be reserved for tables, chairs, etc.

Based upon the Rockwell Phase B estimate, 4,000 lbs of crew/habitability equipment should cost $54 M in 1977 $ for DDT&E, while the TFU would be $6 M.

1.3.1.1.21 Boom

The boom separates the solar array from the main Power Module. It is basically structure, but provides a crawl-way through which personnel may travel to repair the electrical power and distribution system wiring. As reflected by figure X-D-6 it contains 0.1 of an ECLS, 0.2 of an Instrumentation/Communications/Data System and a full environmental protection system. All of these items are costed elsewhere. As indicated by the weight statement the boom weighs 9060 lbs. Based upon the CER in figures 6 & 8, using the S-IC/S-IV structure line, the DDT&E for the boom would be approximately 25 M in 1970 $ and the TFU about $4 M in 1970 $. Converting to 1977 $ these equate to $45 M and $7, respectively.

1.3.1.1.22 Installation, Assembly & Checkout (IACO)

DDT&E

Approach - The equation for the line in figure X-D-31 is complexity factor X 0.15 (TFU) 1.01. Assuming a complexity factor of 1, an estimate of 101 M for IACO of each DDT&E unit results. Assuming one DDT&E unit for major test an estimate for IACO of $101 M in 1977 $ can be assumed.

Theoretical First Unit

Assuming no learning results from the DDT&E unit mentioned above, a TFU of $101 M follows.

1.3.1.1.23 Project Management

The line in Figure X-D-32 represents a multiple regression through the data points on the chart. Use of this CER yields the following cost estimates:

a. DDT&E - $172 M in 1977 $

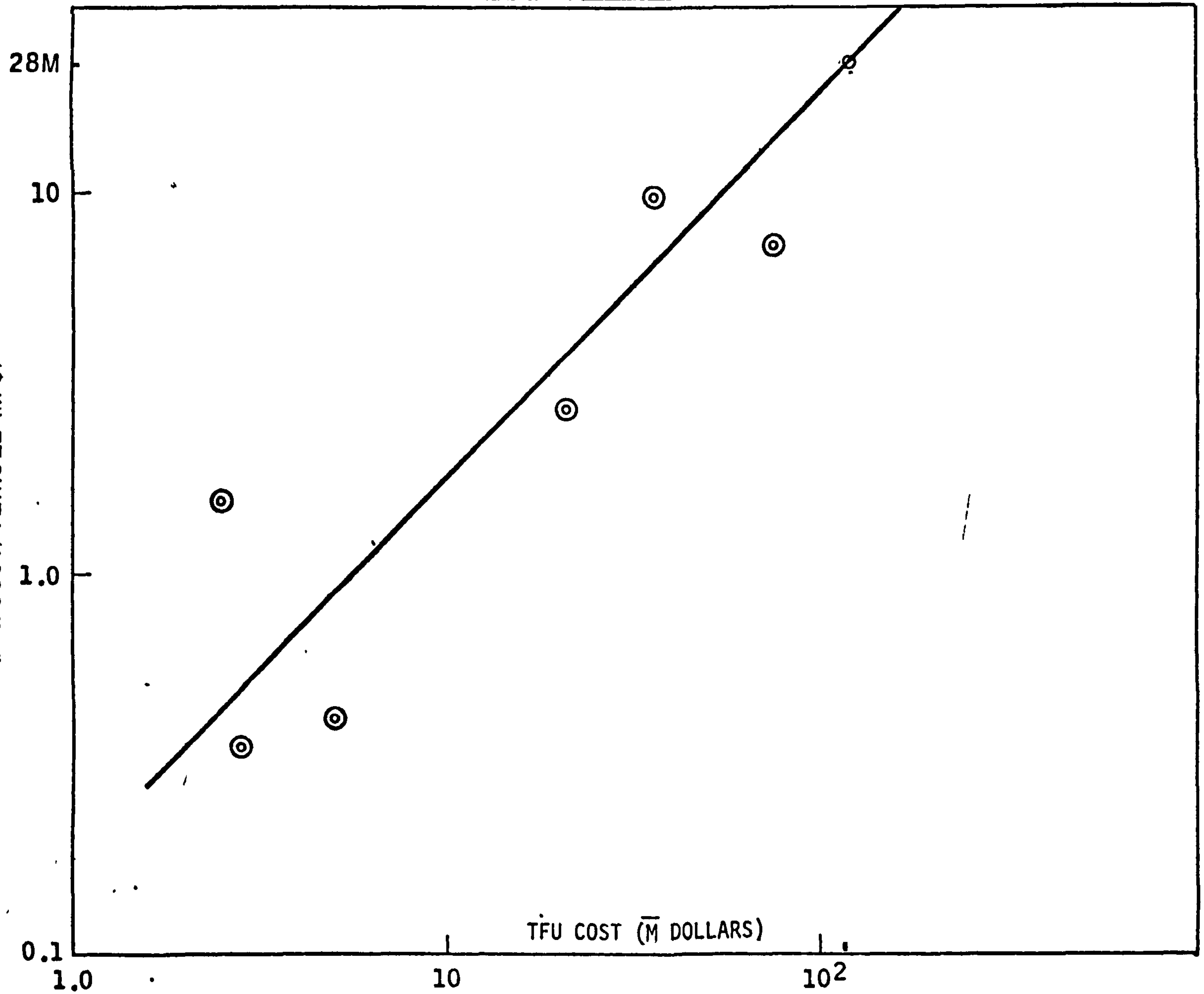
b. TFU - $15 M in 1977 $

1.3.1.1.24 Systems Engineering & Integration (SE&I)

A factor of 7% was used to estimate SE&I costs for the SCB. The following data were used as the basis for selecting 7%:

Program	SE&I (1970 $ in M)	DDT&E (1970 $ in M)	%
Saturn IV-B	65	568	11
Saturn I-C	48	580	7
Saturn II	68	700	10

INSTALLATION AND ASSEMBLY CHECKOUT FIGURE X-D-31



THEORETICAL FIRST UNIT COST

PROJECT MANAGEMENT CER

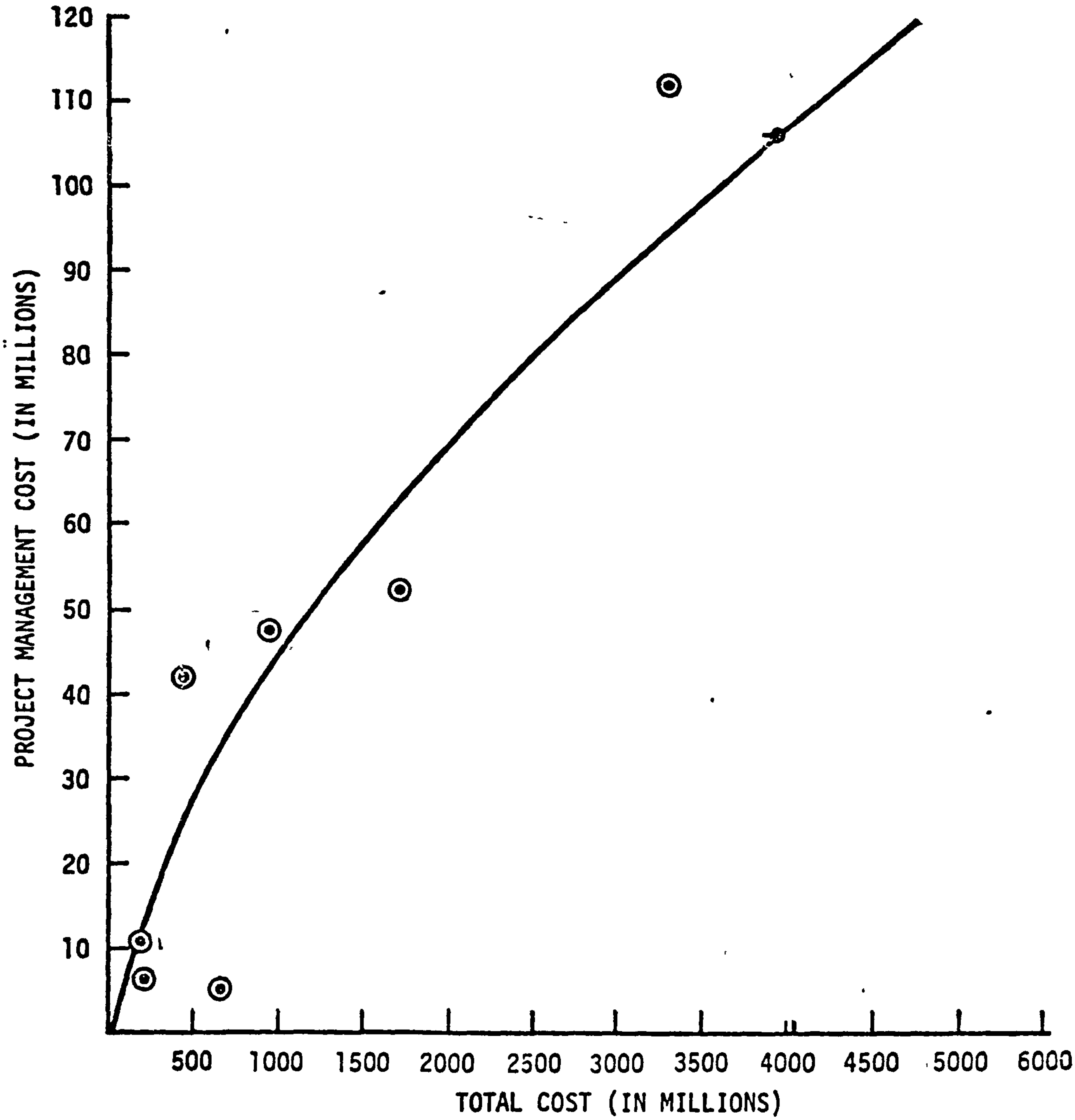


FIGURE X-D-32 PROJECT MANAGEMENT CER

Program	SE&I (1970 $ in M)	DDT&E (1970 $ in M)	%
CSM	150	2300	7
LM	84	1300	7

Applying the 7% to both DDT&E and TFU the following estimates result:

DDT&E	$300 M in 1977 $
TFU	$ 51 M in 1977 $

1.3.1.1.25 Combined Subsystem Development Testing

The amount of testing performed during a program is a function of the desires of the program manager, and the risk he wishes to assume. The following estimates represent the independent judgement of the estimator:

DDT&E	$128 M in 1977 $
TFU	$22 M in 1977 $

1.3.1.1.26 Ground Support Equipment

Historically, GSE has been a large cost driver in NASA programs as indicated by the following data (in various year dollars):

Project	Total	GSE	%
CSM	2.1 B	310 M	15%
LM	1.1 B	143 M	13%
S-IC	780 M	130 M	17%
S-II	660 M	133 M	20%
S-IVB	568 M	107 M	19%

A factor of 4% of DDT&E was used for GSE for both the DDT&E phase and the TFU. In the opinion of the estimator this will be adequate. The SCB will be launched unmanned, the crew being placed into orbit by the PLV. The crew will actuate the SCB in orbit and will have a large volume in which to work and the PLV on-dock at the time. The levels of GSE experienced by the programs above will not be experienced on the SCB. Based upon the 4% the following estimates can be made for GSE:

DDT&E	$172 M
TFU	$26 M

1.3.1.2 SCB Support

This WBS element represents support which can better be provided by NASA than by prime contractors. DDT&E and production costs are discussed together, with separate cost summaries provided in,figures X-D-33 and 34. Operations cost are discussed separately following DDT&E/ Production.

1.3.1.2.1 Crew Training and Simulation

A guideline from the Flight Operations Directorate was that maximum use would be made of on-the-job (OJT) training in space, that the ground training would be kept to a minimum, and that ground simulation & training requirements & equipment would be approximately equal to similar efforts in Shuttle. Using this philosophy an estimate of $133 M was developed for DDT&E. A detailed discussion of this number follows. Since only one of each simulator and trainer were built, no production costs were included.

a. Fabrication and Assembly Simulator - As suggested by the title this facility simulates crew activity in fabrication and assembly operations. The DDT&E estimate of $56 M is the expected run-out cost of the Shuttle Mission Simulator.

b. EVA/IVA Part Task - Regarless of the success of OJT some training in EVA/IVA will be required. The Shuttle Aerospace Simulator was assumed to be similar in size and complexity to the EVA/IVA part-task simulator and the expected OAS cost of $15 M was used.

c. 1-G Trainer - There will be adequate space and people in the (SCB) so that familiarity with that facility will be easily acquired. The 1-G Trainer will be used to aquaint workers of the relative positions of the fabrication and assembly equipment and the SCB. It will contain a very small scale mockup of the SCB and fabrication and assembly hardware. A DDT&E estimate of $12 M, the approximate cost in 1977 $ of the JSC 1-G is trainer, was used.

d. Crew Procedures Development - 1430 MYE at $35,000/year was used to arrive at the $50 M estimate. This effort is similar to the McDonnell-Douglas effort presently being performed for the Space Shuttle Program.

1.3.1.2.2 Test, Evaluation & Analyses

a. Engineering Verification Laboratory (EVL) - this will be a laboratory equal in complexity to the Shuttle Avionics Integration Laboratory (SAIL). It's purposes will be to verify fabrication and assembly concepts, and to ensure compatibility between the SCB and fabrication and assembly hardware. The expected cost of SAIL, in 1977 $ and including Development, Test and Mission Operations (DTMO) support, of $130 M was used as the estimate for the EVL.

FIGURE X-D-33: SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT
PROGRAM SUPPORT - DDT&E
FY 1977 $ IN MILLIONS

	89	90	91	92	93	TOTAL
CREW TRAINING & SIMULATION	13	32	41	36	11	133
FAB & ASSEMBLY SIMULATOR	8	14	16	13	5	56
EVA/IVA PART TASK SIMULATOR	1	4	6	3	1	15
1 G TRAINER	0	2	4	5	1	12
CREW PROCEDURES DEVELOPMENT	4	12	15	15	4	50
TEST & EVALUATION	38	64	85	74	34	295
ENGINEERING VERIFICATION LABORATORY	17	28	39	31	15	130
SOFTWARE DEVELOPMENT LABORATORY	5	7	7	7	4	30
TEST, EVLUATION & ANALYSIS	2	6	8	7	2	25
SAFETY, RELIABILITY & QA	6	10	15	15	4	50
MATERIALS QUALIFICATION	2	3	2	2	1	10
LAB SUPPORT	2	4	6	6	2	20
TEST CHAMBER SUPPORT	1	1	1	1	1	5
IN-LINE SUPPORT	3	5	7	5	5	25
PROGRAM MANAGEMENT	1	3	2	3	1	10
CONFIG. MGT/PM	1	2	2	2	1	8
DATA MGT/SCHED. ETC.	0	1	0	1	0	2
FLIGHT SPT	17	36	43	34	22	152
MISSION CONTROL CENTER MODS	10	20	25	15	10	80
DATA REDUCTION CENTER	1	2	4	4	1	12
MISSION PLANNING	4	10	10	10	6	10
FLIGHT PLANNING	2	4	4	5	5	20
GFE	29	60	68	49	20	226
EMU	6	8	8	8	2	32
PORTABLE O_2 SYSTEM	1	1	2	1	0	5
CCTV	2	5	9	5	2	23
CAMERAS	1	1	1	1	1	5
CREW PROVISIONING & EQUIPMENT	1	1	1	1	1	5
RADIATION MONITORING EQUIPMENT	0	0	1	0	0	1
MANNED MANEUVERING UNIT	3	6	8	6	2	25
SPACE RESCUE & RETRIEVAL VEHICLE	10	30	30	20	10	100
FREE- FLYING TELEVISION	5	8	8	7	2	30
TOTAL	98	195	239	196	88	816

FIGURE X-D-34: SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT
SUMMARY OF TOTAL PRODUCTION COSTS
FY 77 $ IN MILLION

	SCB 1	SCB 2	SCB 3	SCB 4	SCB 5	SCB 6	SCB 7	TOTAL
SCB - SPACE FACILITY	9085	7428	6872	6537	6287	6096	5946	48251
SCB - SUPPORT	94	79	76	76	71	70	68	534
TOTAL	9179	7507	6948	6613	6358	6166	6014	48785

OPERATIONAL DATES FOR SPACE CONSTRUCTION BASES (FY)

SCB 1	1994	SCB 5	2011
SCB 2	2001	SCB 6	2014
SCB 3	2005	SCB 7	2021
SCB 4	2009		

b. Software Development Laboratory (SDL) - The $15 M cost, including DTMO, of the Shuttle SDL was used as the basis for this estimate. Thus might appear to be a small number for 7 SCB's, each with 600 men building a SPS, but $450 M was estimated as the cost of the instrumentation/Communications/Data Management System; Consequently resources have likely been estimated in this overall area.

c. Test, Evaluation and Analyses (TE&A) - $25 M during DDT&E was estumated as the amount required for NASA in-house TE&A. This includes items such as development of components such as sensors, testing of contractor designs, parallel efforts to reduce risk, etc.

d. Safety, Reliability and Quality (SR & QA) Assurance - The estimate of $50 M provides fro an average of 250 people per year at $40,000/year.

e. Materials Qualification - $10 Million over the five year DDT&E period to qualify materials & analyze out-grossing, flammability, etc. It provides for an average of 50 people per year at $40,000 per person.

f. Laboratory Support - The $20 M estimate provides for an average of 100 people per year at $40,000 per person for the 5 year DDT&E.

g. Test Chamber Support - Operation and Maintenance of the JSC Test Chambers will require 25 people per year at rates of $25,000 for maintenance & $30,000 for operation. $5 M for DDT&E was estimated for this effort.

h. In-Line Support - Refers to those efforts performed by NASA and provided to the prime contractors as deliverable products. $25 M for DDT&E was chosen for this estimate.

1.3.1.2.3 Program Management

a. Configuration Management/Performance Management - An average of 32 people per year for DDT&E was assumed for this task. At $50,000 per person per year a DDT&E estimate of $8 M is calculated.

b. Data Management/Scheduling, etc - 10 people per year average of $40,000 per year yields a total DDT&E estimate of $2 M.

1.3.1.2.4 Flight Support

a. Mission Control Center Modifications - A DDT&E estimate of $80 M was selected for the cost of MCC modifications to support the SCB. This estimate was based upon 1/2 of the cost of the MCC Level I update including program and DTMO funds.

b. Data Reduction Center (DRC) - Bulk data processing will be handled by a Data Reduction Center, which will also act somewhat as a backup to the on-board SCB computer. The $12M cost of the Shuttle DRC was used as the estimate for the SCB DRC.

c. Mission Planning - The estimate of $40 M for DDT&E was based upon an average of 200 people per year at $40,000 per person.

d. Flight Planning - 100 people per year at an annual rate of $40,000 was the basis for the $20 M DDT&E estimate for flight planning.

1.3.1.5 Government Furnished Equipment (GFE)

This is the only area of support which has production estimates.

a. Extravehicular Mobility Unit (EMU) - The estimate of 32 M for DDT&E reflects a suit of the same complexity as the one developed for shuttle. Based upon the assumption contained in Table X-D-15 "Quantity Assumptionf for GFE", that 1649 EMU's will be required, or approximately 236 for each SCB, a total production cost of $171 M can be derived by using a a TFU of $250,000.

b. Closed Circuit Television (CCTV) - As indicated by Table X-D-15, there will be 7 CCTV's for each SCB. It was assumed that the CCTV would have the same DDT&E cost as the Shuttle CCTV, $23 M. At a TFU cost of $500,000, approximately the same as the Shuttle CCTV, the 49 SCB units would have a production cost of $12 M.

c. Manned Maneuvering Unit (MMU) - As with the EMU, there will be a total of 1649 MMU's. Because of the mobility required for EVA fabrication and assembly operations it was assumed that a new MMU design would be required, and that this new MMU would have a DDT&E cost of $25 M and a TFU of $125,000. At 90% learning the total production for the 1649 MMU's would be $85 M.

d. Crew Provisions - It was assumed that the DDT&E for all crew provisions would be $5 M, and that $5 M of production items would be required for each SCB.

e. Space Rescue and Retrieval System - A DDT&E estimate of $100 M, and a TFU of $10 M was assumed for this one-man rescue craft with a small set of manipulator arms on the end. It will be a low thrust, minimum range & ECLS vehicle. Two would be required for each SCB, resulting in a production cost of $107 M.

f. Free Flying Television System - This device, which could be in the NASA inventory prior to it's requirement by the SPS program, will be used to investigate areas not readily accessible to EVA crewman or visible to fabrication and assembly operators. A DDT&E estimate of $30 M was assumed and a TFU of $5 M was estimated. It was assumed that each SCB had 2 free flying TV systems, consequently a total production cost of $55 M resulted.

*The following pages contain cost summaries for WBS 1.3.1, Space Construction Base.

TABLE X-D-15

QUANTITY ASSUMPTIONS FOR GFE

Extravehicular Mobility Unit (EMU)

- Of the 600 man crew per SCB, 300 will be EVA qualified, consequently when 7 SCB's are in orbit, 2100 EVA qualified crewmen will require suits.

- EMU's will be designed such that more than one crew person can use the same EMU.

- 200 EMU's can satisfy the EVA requirements for fabrication and assembly of the 300 EVA qualified people per SCB because of multiple shift operation.

- 15% spares will be taken directly from the production line.

- 25 units will be procured for production testing.

- Replacement due to limited shelf life or damage will come out of the operations budget.

- Quantities to be costed are as follows.

Initial Suits for 7 SCB's	1400
15% Spares	224
Production Testing Units	25
Total Production Units	1649

Closed Circuit Television System (CCTV)

Each SCB will have the following number of CCTV units:

1 CCTV for each of 4 Cargo Modules	4
1 CCTV for each Fab & Assembly Module	2
1 CCTV for EVA Preparation & Storage Module	1
Total Per SCB	7

Since there will be 7 SCB's, 49 CCTV production units will be required.

Manned Maneuvering Unit (MMU)

The same logic applies for the MMU as for the EMU, consequently 1649 production units will be required.

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT
SUMMARY OF TOTAL COSTS
FY 77 B IN MILLIONS

DDT&E (BEGINNING IN 1988)	5257
PRODUCTION	48785
OPERATIONS (THROUGH 2025)	21594
TOTAL	75636

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT
SUMMARY OF TOTAL COSTS
FY 77 $ IN MILLIONS

FY	DDT&E	PROD	OPS	TOTAL
1988	373	0		372
1989	976	0		976
1990	1489	1000		2489
1991	1435	2000		3435
1992	813	3000		3813
1993	171	3000		3171
*1994		3000	222	3222
1995		2000	224	2224
1996		2000	224	2224
1997		2000	224	2224
1998		2000	224	2224
1999		2000	224	2224
2000		2000	224	2224
*2001		2000	392	2392
2002		2000	392	2392
2003		2000	392	2392
2004		2000	392	2392
*2005		1000	546	1546
2006		1000	546	1546
2007		1000	548	1548
2008		1000	548	1548
*2009		1000	697	1697
2010		1000	697	1697
*2011		1000	840	1840
2012		1000	840	1840
2013		1000	840	1840
*2014		1000	977	1977
2015		1000	977	1977
2016		1000	977	1977
2017		1000	973	1973
2018		1000	973	1973
2019		1000	973	1973
2020		1000	973	1973
*2021		785	1107	1892
2022			1107	1107

FY	DDT&E	PROD	OPS	TOTAL
23			1107	1107
24			1107	1107
25			1107	1107
TOTAL	5257	48785	21594	75636

* LAUNCH YEAR

SOLAR POWER SATELLITE PROGRAM

SPACE CONSTRUCTION BASE PROJECT

TOTAL DDT&E

FY 1977 $ IN MILLIONS

	88	89	90	91	92	93	TOTAL
SCB FACILITY	274	781	1250	1239	725	171	4441
SCB SUPPORT	98	195	239	196	88	0	816
TOTAL DDT&E	372	976	1489	1435	813	171	5257

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT - SPACE FACILITY

FY 1977 $ IN MILLIONS

DDT&E

	89	90	91	92	93	94	TOTAL
STRUCTURE	8	34	58	58	34	8	200
TOOLING	6	26	44	43	25	6	150
ECLSS	24	102	174	174	102	24	600
RCS	10	42	73	72	43	10	250
ENVIRONMENTAL PROTECTION	6	26	44	43	25	6	150
ELECTRICAL POWER	10	42	73	72	43	10	250
IMS/COMM/DATA	18	77	131	130	76	18	450
STABLIZATION & CONTROL	14	60	102	101	59	14	350
ELEVATOR	2	9	15	14	8	2	50
CARGO TRANSFER SYSTEM	2	9	15	14	8	2	50
CARGO STORAGE STRUCTURE	2	8	14	14	8	2	48
CARGO DEPLOYMENT SYSTEM	4	13	22	21	12	3	75
EVA SUPPORT STATION	2	10	18	18	10	2	60
FOOD MANAGEMENT SYSTEM	5	19	32	32	19	4	111
PHYSICAL FITNESS SYSTEM	3	12	20	20	12	3	70
FABRICATION & ASSEMBLY SYSTEM	12	51	87	87	51	12	300
DOCKING SYSTEM	2	7	12	12	7	1	42
MEDICAL SYSTEM	4	17	29	29	17	4	100
SIMULATION LABORATORY	1	2	4	3	2	1	13
RECREATIONAL SYSTEM	2	9	16	16	9	2	54
BOOM	2	8	13	13	7	2	45
SUBTOTAL HARDWARE	139	583	996	986	577	136	3418
INSTALLATION, ASSEMBLY & CHECKOUT	4	17	30	29	17	4	101
SYSTEMS ENGINEERING & INTEGRATION	12	51	87	87	51	12	300
PROJECT MANAGEMENT	7	29	50	50	29	7	172
SYSTEMS TEST	5	22	37	37	22	5	128
GROUND SUPPORT EQUIPMENT	7	29	50	50	29	7	172
FACILITIES	100	50	0	0	0	0	150
SUBTOTAL FLOATING ITEMS	135	198	254	253	148	35	1023
TOTAL SCB PROJECT	274	781	1250	1239	725	171	4441

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT
PRODUCTION COST BY YEAR
FY 77 $ ROUNDED TO NEAREST BILLION

FY	RATE	CUM
1990	1	1
1991	2	3
1992	3	6
1993	3	9
*1994	3	12
1995	2	14
1996	2	16
1997	2	18
1998	2	20
1999	2	22
2000	2	24
*2001	2	26
2002	2	28
2003	2	30
2004	2	32
2005	1	33
2006	1	34
2007	1	35
2008	1	36
*2009	1	37
2010	1	38
*2011	1	39
2012	1	40
2013	1	41
*2014	1	42
2015	1	43
2016	1	44
2017	1	45
2018	1	46
2019	1	47
2020	1	48
*2021	1	49

SPACE CONSTRUCTION BASE
OPERATIONS PHASE
GROUNDRULES AND ASSUMPTIONS

PROJECT MANAGEMENT - LEVEL EFFORT OF 60 MYE/YEAR AT $50K FOR DURATION OF PROGRAM

SPARES - 3%/YEAR OF IN-USE HARDWARE

LOGISTICS - LEVEL EFFORT OF $2M/YEAR FOR TRANSPUTATION, STORAGE, ETC OF FLIGHT HARDWARE BEFORE IT IS FLOWN. SUPPLEMENTED BY ADDITIONAL $1M/YEAR DURING THE PERIOD 2009 TO 2016 BECAUSE OF HIGHER FLIGHT ACTIVITY.

CREW TRAINING - BASE OF 60 MYE AT $35K/YEAR THROUGHOUT THE OPERATIONS PHASE, SUPPLEMENTED BY 25 ADDITIONAL PEOPLE DURING THE PERIOD 2001 - 2008, AND 60 (FOR A TOTAL OF 120) ADDITIONAL PEOPLE DURING THE PERIOD 2009 -2016.

SAFETY, RELIABILITY & QUALITY ASSURANCE (SR & QA) - LEVEL EFFORT OF 20 MYE AT $40K/YEAR.

FOOD - $1M PER YEAR FOR EACH 600 MAN SCB. THIS EQUATES TO $140/MONTH FOR EACH CREWMAN.

ANOMALY RESOLUTION - 20 MYE/YEAR AT $50,000 FOR RESOLUTION OF ANOMALIES OCCURING DURING OPERATION

MCC OPERAITONS - LEVEL EFFORT OF 40 MYE AT $50K FOR GROUND CONTROL SUPPORT OF AN AUTONOMOUS SCB

MISSION PLANNING - LEVEL EFFORT OF 50 MYE AT $40K. THE MISSIONS WILL NOT VARY SIGNIFICANTLY AS THE ADDITIONAL SCB's ARE PLACED INTO ORBIT.

SIMULATOR OPERATIONS & MAINTENANCE - 60 MYE AT $35K BETWEEN 1994-2005, & 85 MYE FOR THE DURATION OF OPERATIONS.

DATA PROCESSING - A LEVEL EFFORT OF $2M/YEAR, SUPPLEMENTED BY AN ADDITIONAL $1M/YEAR DURING THE PERIOD 2006 - 2016.

SUSTAINING ENGINEERING - A LEVEL EFFORT OF 40 MYE AT $50K.

GOVERNMENT FURNISHED EQUIPMENT - 2%/YEAR OF PRODUCTION COST OF IN-USE GFE.

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT - SUPPORT
OPERATIONS COST
FY 77 $ IN MILLIONS

	94	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	10	11	12
PROJECT MANAGEMENT	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
SPARES	202	202	202	202	202	202	202	367	367	367	367	519	519	519	519	664	664	804	804
LOGISTICS	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3
CREW TRAINING	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4
SR & QA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FOOD	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4	4	5	5
ANOMALY RESOLUTION	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MCC OPERATIONS	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
MISSION PLANNING	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SIMULATOR OPERATIONS & MAINTENANCE	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
DATA PROCESSING	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
SUSTAINING ENGINEERING	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
GFE	2	2	2	2	2	2	2	3	3	3	3	4	4	4	4	5	5	7	7
TOTAL	222	224	224	224	224	224	224	392	392	392	392	546	546	548	548	697	697	840	840

(CONT.)

	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
PROJECT MANAGEMENT	3	3	3	3	3	3	3	3	3	3	3	3	3	94
SPARES	804	939	939	939	939	939	939	939	1071	1071	1071	1071	1071	20626
LOGISTICS	3	3	3	3	2	2	2	2	2	2	2	2	2	72
CREW TRAINING	4	4	4	4	2	2	2	2	2	2	2	2	2	88
SR & QA	1	1	1	1	1	1	1	1	1	1	1	1	1	32
FOOD	5	6	6	6	6	6	6	6	7	7	7	7	7	127
ANOMALY RESOLUTION	1	1	1	1	1	1	1	1	1	1	1	1	1	32
MCC OPERATIONS	2	2	2	2	2	2	2	2	2	2	2	2	2	64
MISSION PLANNING	2	2	2	2	2	2	2	2	2	2	2	2	2	64
SIMULATOR OPERATIONS & MAINTENANCE	3	3	3	3	3	3	3	3	3	3	3	3	3	83
DATA PROCESSING	3	3	3	3	2	2	2	2	2	2	2	2	2	74
SUSTAINING ENGINEERING	2	2	2	2	2	2	2	2	2	2	2	2	2	64
GFE	7	8	8	8	8	8	8	8	9	9	9	9	9	174
TOTAL	840	977	977	977	973	973	973	973	1107	1107	1107	1107	1107	21594

NASA-S-77-11133

SPACE CONSTRUCTION BASE - SPACE FACILITY
COMPARISON OF ESTIMATES - DDT&E
FY 77 $ IN MILLIONS

SUBSYSTEM NUMBER	SUBSYSTEM	NUMBER OF ESTIMATES MODE	HIGH ESTIMATE	LOW ESTIMATE	MEAN ESTIMATE	SELECTED ESTIMATE
1 3 1 1 1	STRUCTURE	4	433	187	273	200
1 3 1 1 2	ECLSS	2	1224	597	641	600
1 3 1 1 3	RCS	7	750	73	329	250
1 3 1 1 4	ENVIRONMENTAL PROTECTION	2	156	107	132	150
1 3 1 1 5	TOOLING	1	150	150	150	150
1 3 1 1 6	STAB AND CONTROL	3	821	171	517	350
1 3 1 1 7	INST COMM DATA	3	793	446	562	450
1 3 1 1 8	EPS	2	480	247	364	250
1 3 1 1 9	ELEVATOR	1	50	50	50	50
1 3 1 1 10	CARGO TRANSFER SYSTEM	1	50	50	50	50
1 3 1 1 11	CARGO STORAGE STRUCTURE	1	48	48	48	48
1 3 1 1 12	CARGO DEPLOYMENT SYSTEM	1	75	75	75	75
1 3 1 1 13	EVA SUPPORT STATION	1	60	60	60	60
1 3 1 1 14	FOOD MANAGEMENT SYSTEM	1	111	111	111	111
1 3 1 1 15	PHYSICAL FITNESS SYSTEM	1	70	70	70	70
1 3 1 1 16	FABRICATION AND ASSEMBLY SYSTEM	1	300	300	300	300
1 3 1 1 17	DOCKING SYSTEM	1	42	42	42	42
1 3 1 1 18	MEDICAL SYSTEM	1	100	100	100	100
1 3 1 1 19	SIMULATION LABORATORY	1	13	13	13	13
1 3 1 1 20	RECREATIONAL SYSTEM	1	54	54	54	54
1 3 1 1 21	BOOM	1	45	45	45	45
1 3 1 1 22	INSTALLATION ASSEMBLY AND CHECKOUT	1	101	101	101	101
1 3 1 1 23	PROJECT MANAGEMENT	1	172	172	172	172
1 3 1 1 24	SYSTEMS ENGINEERING AND INTEGRATION	1	300	300	300	300
1 3 1 1 25	COMBINED SUBSYSTEMS DEVELOPMENT TESTING	1	128	128	128	128
1 3 1 1 26	GSE	1	172	172	172	172
1 3 1 1 27	FACILITIES	1	150	150	150	150
	TOTAL		6848	4019	5209	4441

SPACE CONSTRUCTION BASE - SPACE FACILITY
COMPARISON OF ESTIMATES - TFU
1977 $ IN MILLIONS

SUBSYSTEM NUMBER	SUBSYSTEM	NUMBER OF ESTIMATES MADE	HIGH ESTIMATE	LOW ESTIMATE	MEAN ESTIMATE	SELECTED ESTIMATE
1.3.1.1.1	STRUCTURE	4	140	18	71	60
1.3.1.1.2	ECLSS	3	202	79	121	80
1.3.1.1.3	RCS	5	90	28	62	70
1.3.1.1.4	ENVIRONMENTAL PROTECTION	2	62	50	56	50
1.3.1.1.5	TOOLING	1	20	20	20	20
1.3.1.1.6	STAB. & CONTROL	6	426	40	155	100
1.3.1.1.7	INST/COMM/DATA	3	384	43	166	50
1.3.1.1.8	EPS	1	73	73	73	73
1.3.1.1.9	ELEVATOR	1	3	3	3	3
1.3.1.1.10	CARGO TRANSFER SYSTEM	1	3	3	3	3
1.3.1.1.11	CARGO STORAGE SYSTEM	1	7	7	7	7
1.3.1.1.12	CARGO DEPLOYMENT SYSTEM	1	5	5	5	5
1.3.1.1.13	EVA SUPPORT SYSTEM	1	10	10	10	10
1.3.1.1.14	FOOD MANAGEMENT SYSTEM	1	15	15	15	15
1.3.1.1.15	PHYSICAL FITNESS SYSTEM	1	9	9	9	9
1.3.1.1.16	FABRICATION & ASSEMBLY SYSTEM	1	33	33	33	33
1.3.1.1.17	DOCKING SYSTEM	1	14	14	14	14
1.3.1.1.18	MEDICAL SYSTEM	1	12	12	12	12
1.3.1.1.19	SIMULATION LABORATORY	1	12	12	12	12
1.3.1.1.20	RECREATIONAL SYSTEM	1	6	6	6	6
1.3.1.1.21	BOOM	1	7	7	7	7
1.3.1.1.22	INSTALLATION, ASSEMBLY, & CHECKOUT	1	101	101	101	101
1.3.1.1.23	PROJECT MANAGEMENT	1	15	15	15	15
1.3.1.1.24	SYSTEMS ENGINEERING & INTEGRATION	1	51	51	51	51
1.3.1.1.25	COMBINED SUBSYSTEMS DEVELOPMENT TESTING	1	22	22	22	22
1.3.1.1.26	GSE	1	26	26	26	26
1.3.1.1.27	FACILITIES	-	-	-	-	-
	15% FOR INITIAL SPARES	1	300	73	129	95
	TOTAL	44	2048	775	1204	951

NASA-S-77-3261

SOLAR POWER SATELLITE
SPACE CONSTRUCTION BASE
ASSIGNMENT OF SUBSYSTEMS (IN EQUIVALENT UNITS)
PRODUCTION HARDWARE ONLY

ELEMENT	SCB 1	SCB 2	SCB 3	SCB 4	SCB 5	SCB 6	SCB 7
STRUCTURES	UNITS 1-27	28-54	55-81	82-108	109-135	136-162	163-189
TOOLING	2 LINES	0	0	0	0	0	0
ECLS	1-19	20-38	39-57	58-76	77-95	96-144	115-133
RCS	1-12	13-24	25-36	37-48	49-60	61-72	73-84
ENVIRONMENTAL PROTECTION	1-27	29-54	57-81	85-108	113-135	141-162	169-189
EPS	1-14	15-28	29-42	43-56	57-70	71-84	85-98
IMS/COMM/DATA	1-14	15-28	29-42	43-56	57-70	71-84	85-98
STAB & CONTROL	1-12	13-24	25-36	37-48	49-60	61-72	73-84
BOOM	1	2	3	4	5	6	7
ELEVATOR	1-4	5-8	9-12	13-16	17-20	21-24	25-28
CARGO TRANSFER SYSTEM	1-4	5-8	9-12	13-16	17-20	21-24	25-28
CARGO STORAGE SYSTEM	1-4	5-8	9-12	13-16	17-20	21-24	25-28
CARGO DEPLOYMENT SYSTEM*	1-4	5-8	9-12	13-16	17-20	21-24	25-28
EVA SUPPORT STATION	1	2	3	4	5	6	7
FOOD MANAGEMENT SYSTEM	1	2	3	4	5	6	7
PHYSICAL FITNESS SUBSYSTEM	1	2	3	4	5	6	7
FABRICATION AND ASSEMBLY SYSTEM	1-2	3-4	5-6	7-8	9-10	11-12	13-14
MATERIAL DEPLOYMENT SYSTEM*	29-30	31-32	33-34	35-36	37-38	39-40	41-42
DOCKING STRUCTURE SYSTEM	1-41	42-82	83-123	124-164	165-205	206-246	247-287
MEDICAL SYSTEM	1	2	3	4	5	6	7
SIMULATION FACILITY	1	2	3	4	5	6	7
RECREATIONAL FACILITY	1	2	3	4	5	6	7

*LOCATED BOTH CARGO MODULES & FABRICATION & ASSEMBLY MODULES

SOLAR POWER SATELLITE
SPACE CONSTRUCTION BASE
SUMMARY OF SUBSYSTEM COSTS - SPACE FACILITY
FY 77 $ IN MILLIONS
90% LEARNING

	TFU	SCB 1	SCB 2	SCB 3	SCB 4	SCB 5	SCB 6	SCB 7	TOTAL
STRUCTURE	60	1135	924	854	812	781	757	739	6002
TOOLING	20	40	0	0	0	0	0	0	40
ECLS	80	1118	914	845	803	773	749	731	5932
RCS	70	656	541	500	475	458	444	433	3507
ENVIRONMENTAL PROTECTION	50	946	770	712	676	651	631	615	5001
EPS	73	783	643	595	565	544	528	515	4173
IMS/COMM/DATA	50	536	441	407	387	373	361	352	2857
STAB & CONTROL	100	937	773	715	679	654	634	618	5010
BOOM	7	7	6	6	6	6	6	6	43
ELEVATOR	3	11	9	8	8	8	7	7	58
CARGO TRANSFER SYSTEM	3	11	9	8	8	8	7	7	58
CARGO STORAGE STRUCTURE	7	25	21	20	19	18	17	17	137
CARGO DEPLOYMENT SYSTEM	5*	18	15	14	13	13	12	12	97
EVA SUPPORT STATION	10	10	10	9	9	9	8	8	63
FOOD MANAGEMENT SYSTEM	15	15	14	14	13	13	13	13	95
PHYSICAL FITNESS SYSTEM	9	9	9	8	8	8	8	8	58
FABRICATION AND ASSEMBLY SYSTEM	33	63	55	51	49	47	46	44	355
MATERIAL DEPLOYMENT SYSTEM	(5)*	6	6	6	6	6	6	6	42
DOCKING SYSTEM	14	379	308	284	270	253	246	239	1979
MEDICAL SYSTEM	12	12	11	11	11	10	10	10	75
SIMULATION FACILITY	12	12	11	11	11	10	10	10	75
RECREATIONSAL SYSTEMS	6	6	6	5	5	5	5	5	37
TOTAL SUBSYSTEMS	632	6735	5496	5083	4833	4648	4505	4395	35694
SPARES (15%)	95	1009	824	762	724	696	675	658	5348
TOTAL HARDWARE	734	7744	6320	5845	5557	5344	5180	5053	41042
INSTALLATION, ASSEMBLY & CHECKOUT	16%**	101	96	92	90	88	86	84	637
SYSTEM ENGINEERING & INTEGRATION	7%	542	442	409	389	374	363	353	2872
PROJECT MANAGEMENT	2%*	155	127	117	112	107	104	101	823
SYSTEMS TEST	3%	233	190	175	167	160	155	152	1232
GSE	4%	310	253	234	222	214	207	203	1643
TOTAL PRODUCTION	951	9085	7428	6872	6537	6287	6096	5946	48251

*TFU FOR CARGO DEPLOYMENT SYSTEM & MATERIAL DEPLOYMENT SYSTEM THE SAME & INCLUDED IN CARGO DEPLOYMENT SYSTEM. UNITS 1-28 ASSIGNED TO THE CARGO MODULES & 29-42 TO THE FABRICATION AND ASSEMBLY MODULES.

**APPROXIMATE PERCENTAGES BASED ON CER's FIGURES 30 AND 31. THE 16% DOES NOT INCLUDE IA&CO OF SPARES.

SOLAR POWER SATELLITE PROGRAM
SPACE CONSTRUCTION BASE PROJECT - SUPPORT
SUMMARY OF GFE PRODUCTION COSTS
FY 77 $ IN MILLIONS

	QUANTITY PER SCB	TFU	SCB 1	SCB 2	SCB 3	SCB 4	SCB 5	SCB 6	SCB 7	TOTAL
EMU	236	0.25	30	24	24	24	23	23	23	171
CCTV	7	0.5	3	2	2	2	1	1	1	12
SPACE RESCUE & RETRI-EVAL SYSTEM	2	10	19	17	15	15	14	14	13	107
MMU	236	0.125	15	12	12	12	12	11	11	85
FREE FYLYING TV SYSTEMS	2	5	10	9	8	8	7	7	6	55
CREW PROVISIONS	-	1	5	5	5	5	5	5	5	35
SUBTOTAL	-	17	82	69	66	66	62	61	59	465
15% SPARES	-		12	10	10	10	9	9	9	69
TOTAL GFE PRODUCTION	-	17	94	79	76	76	71	70	68	534

WBS 1.3.1
SPACE CONSTRUCTION BASE
COST ESTIMATING METHODOLOGY
FY 1977 $ IN MILLIONS

SUBSYSTEM-PHASE	APPROACH	ESTIMATES	ESTIMATE CHOSEN
1.3.1.1.1 Structure - DDT&E	JSC Aircraft CER + Complexity Factor	$203 M	$ 200 M
	JSC Booster CER + Complexity Factor	$187 M	
	Scaling MDAC Phase B Cost	$269 M	
	Scaling Rockwell Phase B Cost	$433 M	
Structure TFU	JSC Aircraft CER + Complexity Factor	$ 52 M	$ 60 M
	JSC Booster CER + Complexity Factor	$ 18 M	
	Scaling MDAC Phase B Cost	$ 73 M	
	Scaling Rockwell Phase B Cost	$140 M	
1.3.1.1.2 Environmental Control - DDT&E	JSC CER	$1224 M	$ 600 M
	Planning Research Corp. CER	$597 M	
	Scaling Rockwell Phase B Cost	$702 M	
Environmental Control - TFU	JSC CER	$ 82 M	$ 80 M
	Scaling MDAC Phase B Cost	$ 36 M	
	Scaling Rockwell Phase B Cost	$ 92 M	
1.3.1.1.3 Reaction Control System - DDT&E	Rockwell CER	$740 M	$ 250 M
	Scaling of Gemini Data	$177 M	
	Scaling of Apollo Block I Data	$750 M	
	MDAC Phase B Scaling	$ 73 M	
	Rockwell Phase B Scaling	$134 M	
	JSC CER - CSM Line	$262 M	
	JSC CER - LM Line	$169 M	

SUBSYSTEM-PHASE	APPROACH	ESTIMATES	ESTIMATE CHOSEN
Reaction Control System - TFU	Rockwell CER	$ 56 M	$ 70 M
	JSC CER - LM Line	$ 62 M	
	JSC CER - CSM Line	$ 90 M	
	Rockwell Phase B Scaling	$ 73 M	
	MDAC Phase B Scaling	$ 28 M	
1.3.1.1.4 Environmental Protection - DDT&E	Rockwell CER	$156 M	$ 50 M
	Rockwell Phase B Scaling	$107 M	
Environmental Protection - TFU	Rockwell CER	$ 50 M	$ 150 M
	Rockwell Phase B. Scaling	$ 62 M	
1.3.1.1.5 Tooling - DDT&E	JSC CER + Complexity Factor	$150 M	$ 150 M
Tooling - TFU	Apollo Factor of 3.6% of TFU	$ 20 M	$ 20 M
1.3.1.1.6 Stabilization & Control - DDT&E	Rockwell CER	$821 M	$ 350 M
	Scaling of Rockwell Phase B	$559 M	
	Scaling of MDAC Phase B	$171 M	
Stabilization & Control - TFU	Rockwell CER	$127 M	$ 100 M
	JSC CER - Gemini Line	$ 43 M	
	JSC CER - LM Line	$426 M	
	Scaling of Rockwell Phase B	$112 M	
	Scaling of MDAC Phase B	$ 40 M	
	JSC CER - CM Line	$181 M	

SUBSYSTEM-PHASE	APPROACH	ESTIMATES	ESTIMATE CHOSEN
1.3.1.1.7 Instrumentation/ Communications/Data - DDT&E	JSC CER's	$446 M	$ 450 M
	Scaling of Rockwell Phase B	$793 M	
	Scaling of MDAC Phase B	$446 M	
Instrumentation/Communica- tions/Data - TFU	JSC CER's	$ 43 M	$ 50 M
	Scaling of Rockwell Phase B	$384 M	
	Scaling of MDAC Phase B	$ 72 M	
1.3.1.1.8 Electrical Power Subsystem - DDT&E	Scaling of Rockwell Phase B	$480 M	$ 250 M
	JSC Adjusted Rockwell Phase B	$247 M	
Electrical Power Subsystem - TFU	JSC Adjustment to Rockwell Phase B	$ 73 M	$ 73 M
1.3.1.1.9 Elevator - DDT&E	Planning Research Corp CER for Landing Gear	$ 50 M	$ 50 M
Elevator - TFU	Planning Research Corp CER for Landing Gear	$ 3 M	$ 3 M
1.3.1.1.10 Cargo Transfer System - DDT&E	Planning Research Corp CER for Landing Gear	$ 50 M	$ 50 M
Cargo Transfer System - TFU	Planning Research Corp CER for Landing Gear	$ 3 M	$ 3 M
1.3.1.1.11 Cargo Storage System - DDT&E	JSC Booster Structure CER	$ 48 M	$ 48 M

SUBSYSTEM-PHASE	APPROACH	ESTIMATES	ESTIMATE CHOSEN
Cargo Storage System - TFU	JSC Booster Structure CER	$ 7 M	$ 7 M
1.3.1.1.12 Cargo Deployment System - DDT&E	Same cost as Shuttle RMS	$ 75 M	$ 75 M
Cargo Deployment System - TFU	Same Cost as Shuttle RMS	$ 5 M	$ 5 M
1.3.1.1.13 EVA Support Station - DDT&E	Scaling of Rockwell Phase B	$ 60 M	$ 60 M
EVA Support Station - TFU	Scaling of Rockwell Phase B	$ 10 M	$ 10 M
1.3.1.1.14 Food Management-DDT&E	Scaling of Rockwell Phase B	$111 M	$ 111 M
Food Management - TFU	Scaling of Rockwell Phase B	$ 15 M	$ 15 M
1.3.1.1.15 Physical Fitness System - DDT&E	Scaling of Rockwell Phase B	$ 70 M	$ 70 M
Physical Fitness System - TFU	Scaling of Rockwell Phase B	$ 9 M	$ 9 M
1.3.1.1.16 Fabrication & Assembly System - DDT&E	1.5 X Beam Builder Cost	$300 M	$ 300 M
Fabrication & Assembly System - TFU	1.5 X Beam Builder Cost	$ 33 M	$ 33 M
1.3.1.1.17 Docking System-DDT&E	JSC Structure CER/PRC ECLSS CER	$ 42 M	$ 42 M

SUBSYSTEM-PHASE	APPROACH	ESTIMATES	ESTIMATE CHOSEN
Docking System - TFU	JSC Structure CER/PRC ECLSS CER	$ 14 M	$ 14 M
1.3.1.1.18 Medical System - DDT&E	Scaling of Rockwell Phase B	$100 M	$ 100 M
Medical System - TFU	Scaling of Rockwell Phase B	$ 12 M	$ 12 M
1.3.1.1.19 Simulation Laboratory - DDT&E	25% of Ground Simulators	$ 13 M	$ 13 M
Simulation Laboratory - TFU	Adjusted Unit Cost of Ground Sims	$ 12 M	$ 12 M
1.3.1.1.20 Recreational Systems - DDT&E	Scaling of Rockwell Phase B	$ 54 M	$ 54 M
Recreational Systems - TFU	Scaling of Rockwell Phase B	$ 6 M	$ 6 M
1.3.1.1.21 Boom - DDT&E	JSC Booster Structure CER	$ 45 M	$ 45 M
Boom - TFU	JSC Booster Structure CER	$ 7 M	$ 7 M
1.3.1.1.22 Installation, Assembly & Checkout - DDT&E	JSC CER	$101 M	$ 101 M
Installation, Assembly & Checkout - TFU	JSC CER	$101 M	$ 101 M

SUBSYSTEM - PHASE	APPROACH	ESTIMATES	ESTIMATE CHOSEN
1.3.1.1.23 Project Management - DDT&E	JSC CER	$172 M	$ 172 M
Project Management - TFU	JSC CER	$ 15 M	$ 15 M
1.3.1.1.24 Systems Engineering & Integration - DDT&E	7 % OF SCB DDT&E	$300 M	$ 300 M
Systems Engineering & Integration - TFU	7 % of SCB TFU	$ 51 M	$ 51 M
1.3.1.1.25 Combined Subsystem Development Testing-DDT&E	3 % of SCB DDT&E	$128 M	$ 128 M
Combined Subsystem Development Testing - TFU	3 % of SCB TFU	$ 22 M	$ 22 M
1.3.1.1.26 Ground Support Equipment - DDT&E	4 % of SCB DDT&E	$172 M	$ 172 M
Ground Support Equipment - TFU	4 % of SCB TFU	$ 26 M	$ 26 M
1.3.1.1.27 Facilities - DDT&E	Scaling of Rockwell Phase B	$150 M	$ 150 M
Facilities - TFU	Scaling of Rockwell Phase B	0	0
1.3.1.1 Total			$4441 M

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WBS 1.3.1 SPACE CONSTRUCTION BARE BARE
SUMMARY OF TOTAL MANPOWER COST
FY 77 $ IN MILLIONS - $50K/PERSON/YEAR

FISCAL YEAR	SCB 1		SCB 2		SCB 3		SCB 4		SCB 5		SCB 6		SCB 7		TOTAL	
	PEOPLE	$	PEOPLE	$	PEOPLE	$	PEOPLE	$	PEOPLE	$	PEOPLE	$	PEOPLE	$	PEOPLE	$
1994	600	30													600	30
95																
96																
97																
98																
99																
2000																
01			600	30											1200	60
02																
03																
04																
05					600	30									1800	90
06																
07																
08																
09							600	30							2400	120
10																
11									600	30					3000	150
12																
13																
14											600	30			3600	180
15																
16																
17																
18																
19																
20																
21													600	30	4200	210
22																
23																
24																
25	600	30	600	30	600	30	600	30	600	30	600	30	600	30	4200	210
TOTAL	19200	960	15000	750	12600	630	10200	510	9000	450	7200	360	3000	150	76200	3810

WBS 1.3.2 AND WBS 1.3.3

FABRICATION AND ASSEMBLY

ANALYST: T. S. FOSTER

INTRODUCTION

Table X-D-16 contains the Work Breakdown Structure (WBS) for Satellite Fabrication and Assembly (1.3.2) and Antenna Fabrication and Assembly (1.3.3). These projects include the design, development, production, and maintenance (operations are excluded) of the orbital tooling used to construct SPS in low earth orbit.

General Cost Methodology

Costs included herein are based on parameters and guidelines provided by the Spacecraft Design Division at JSC.

Because Space Fabrication and Assembly is as yet an untested concept, aerospace cost data for such systems is not readily available. In addition, the SPS fabrication and assembly concept is in its earliest stages of definition. Hence, subsystem costing in the literal sense is not feasible. For these reasons, it is necessary to depart from "normal" parametric costing techniques. The method used, therefore, is summarized as follows:

First, approximate weights and subsystem analogies (Table X-D-17) for each system were supplied by the Spacecraft Design Division. A figure representing the percentage of the total system which is "like" the subsystem analogy was assigned to each analogy. The Beam Builder, for instance, was assumed to be similar in function and complexity to an aerospace system consisting of Structural Framework (43%), Landing Gear (40%), Environmental Control (15%), and Displays and Controls (2%). Each percentage was then multiplied by the total system weight to obtain a weight for each analogy. These were costed using parametric techniques, as if they were subsystems. Various cost estimating relationships, scaling factors, and other techniques were used. The cost of the system is found by simply adding together the costs of each subsystem analogy.

Other costing methodologies are summarized on WBS 1.3.1.

1.3.2.1 Beam Builder

The Solar Collector Beam Builder will rely heavily on mechanical and hydraulic control surfaces, structural elements, thermal control devices, and various electrical subsystems. It is assumed to be similar in function and complexity to a weighted composite of the aerospace subsystems listed below. Percentage weighting factors are shown in parentheses.

TABLE X-D-16

WORK BREAKDOWN STRUCTURE

WBS 1.3.2 and WBS 1.3.3

1.3.2	Solar Collector Fabrication and Assembly Project
1.3.2.1	Beam Builder
1.3.2.2	Reflector Installer
1.3.2.3	Solar Cell Blanket Installer
1.3.2.4	Conductor Installer
1.3.2.5	Mobile Manipulator
1.3.2.6	Dock Module
1.3.3	Antenna Fabrication and Assembly Project
1.3.3.1	Antenna Beam Builder
1.3.3.2	Antenna Conductor Installer
1.3.3.3	Antenna Subarray Installer

COST ESTIMATED RELATIONSHIPS (CER) INPUTS

FABRICATION AND ASSEMBLY

Item	Number Required GEO System	LEO System	Weight Each	Subsystem Analogy Complexity Factor
COLLECTOR				
1. Beam Builder (10 Meter)	57	15	5000 kg	ECS, landing gear, control surfaces
2. Installers				
- Reflector	8	2	10000 kg	Gantry crane, landing gear
- Solar Cell Blankets	4	1	10000 kg	
3. Conductor Installers (Harness Builders)	8	2	5000 kg	Manipulator, landing gear
4. Mobile Manipulator	19	5	5000 kg	Manipulator, LM cabin
5. Docking modules		2	5000 kg	Docking, landing gear, SCS
ANTENNA				
1. Beam Builder (0.2 Meter)	18	18	1000 kg	ECS, landing gear, control surfaces
2. Conductor Installers	4	4	5000 kg	Manipulator, landing gear
3. Subarray installers	4	4	5000 kg	Manipulator, LM cabin
4. Subarray manufacturing	8	8	10000 kg	Manipulator, space manufacturing

a. Structural Framework (43%)
b. Landing Gear (40%)
c. Environmental Control (15%)
e. Displays and Controls (2%)

Aerospace Cost Estimating Relationships were used to cost Structural Framework, Landing Gear, and ECS. CER's selected for costing Structural Framework (fig. X-D-35 and 36) and Landing Gear (fig. X-D-37 & 38)were derived by Planning Research Corporation (PRC) of Huntsville, Alabama. The Environmental Control CER was developed by JSC for the Shuttle 040C Agency Commitment Estimate (fig. X-D-39 & 40). Displays and Controls were costed by the RCA Price Model.

Assuming a total weight of 11,000 lbs., the following costs were derived:

DDT&E

Structural Framework	30 M (1975 $'s)
Landing Gear	8 M (1975 $'s)
ECS	59 M (1970 $'s)
Displays and Controls	9 M (1977 $'s)

TFU

Structural Framework	2 M (1975 $'s)
Landing Gear	2 M (1975 $'s)
ECS	9 M (1970 $'s)
Displays and Controls	9 M (1977 $'s)

Escalation to 1977 $'s results in the following cost estimate:

DDT&E	162 M
TFU	29 M

1.3.2.2 Reflector Installer

The Reflector Installer is conceived to be a large (22000 lbs), open structure with some moveable parts. It would be of fairly simple design and is assumed to be similar in function and complexity to a composite of the following aerospace subsystems.

a. Structural Framework 84%
b. Landing Gear 15%
c. ECS 1%

The PRC CER's for Structural Framework and Landing Gear, and the Shuttle ECS CER may be used to derive the following costs:

FIGURE X-D-35

STRUCTURAL FRAMEWORK

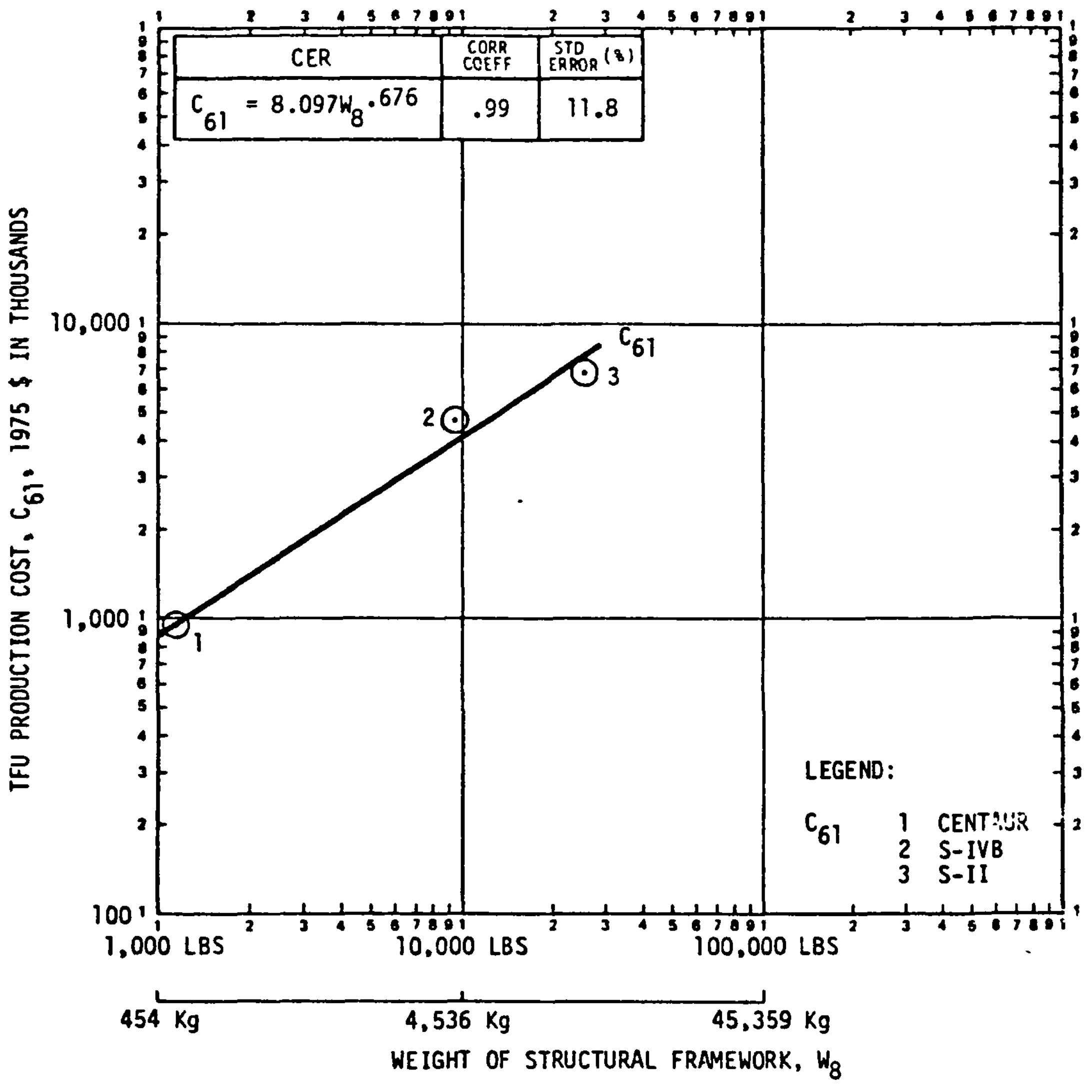
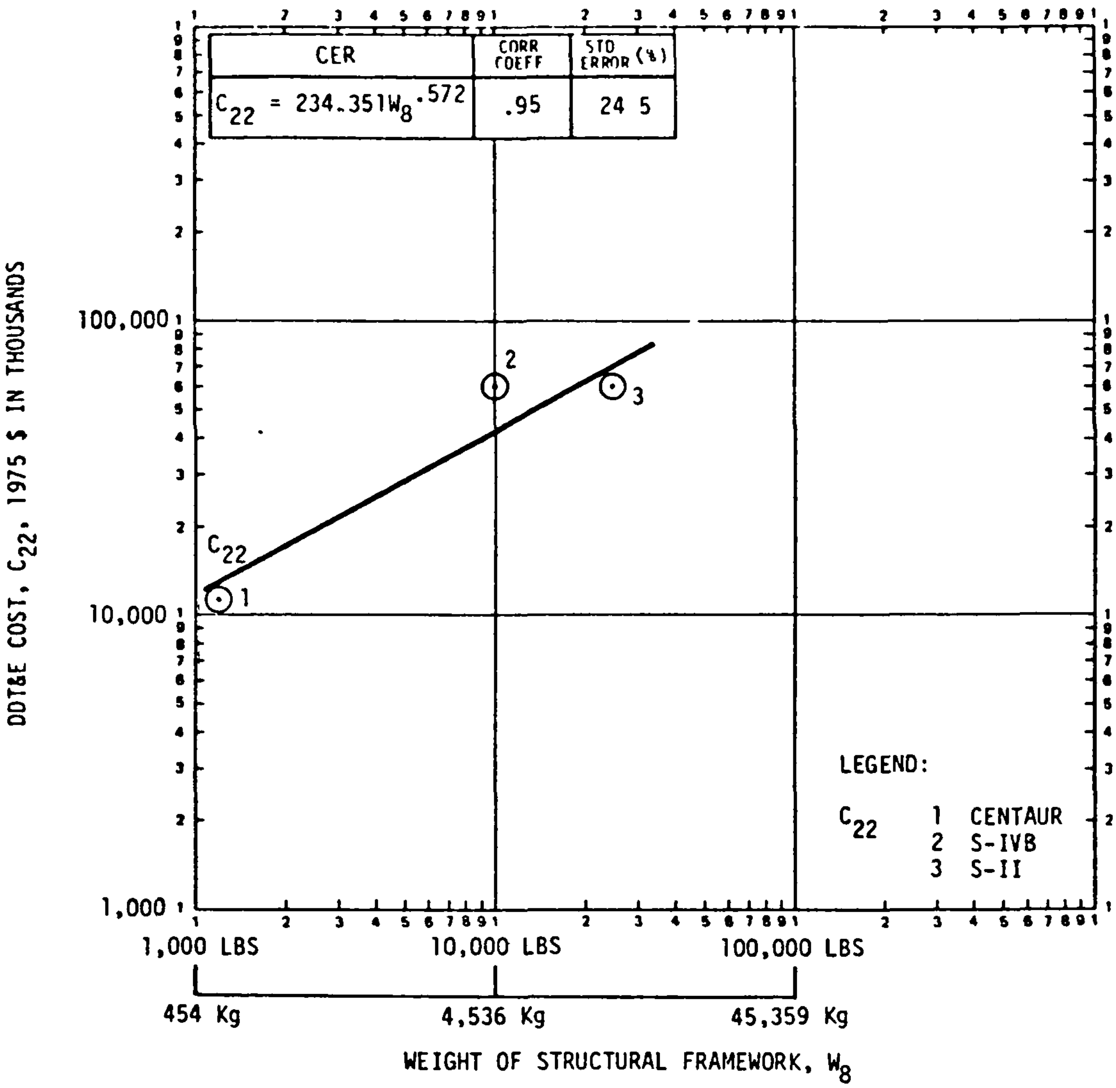
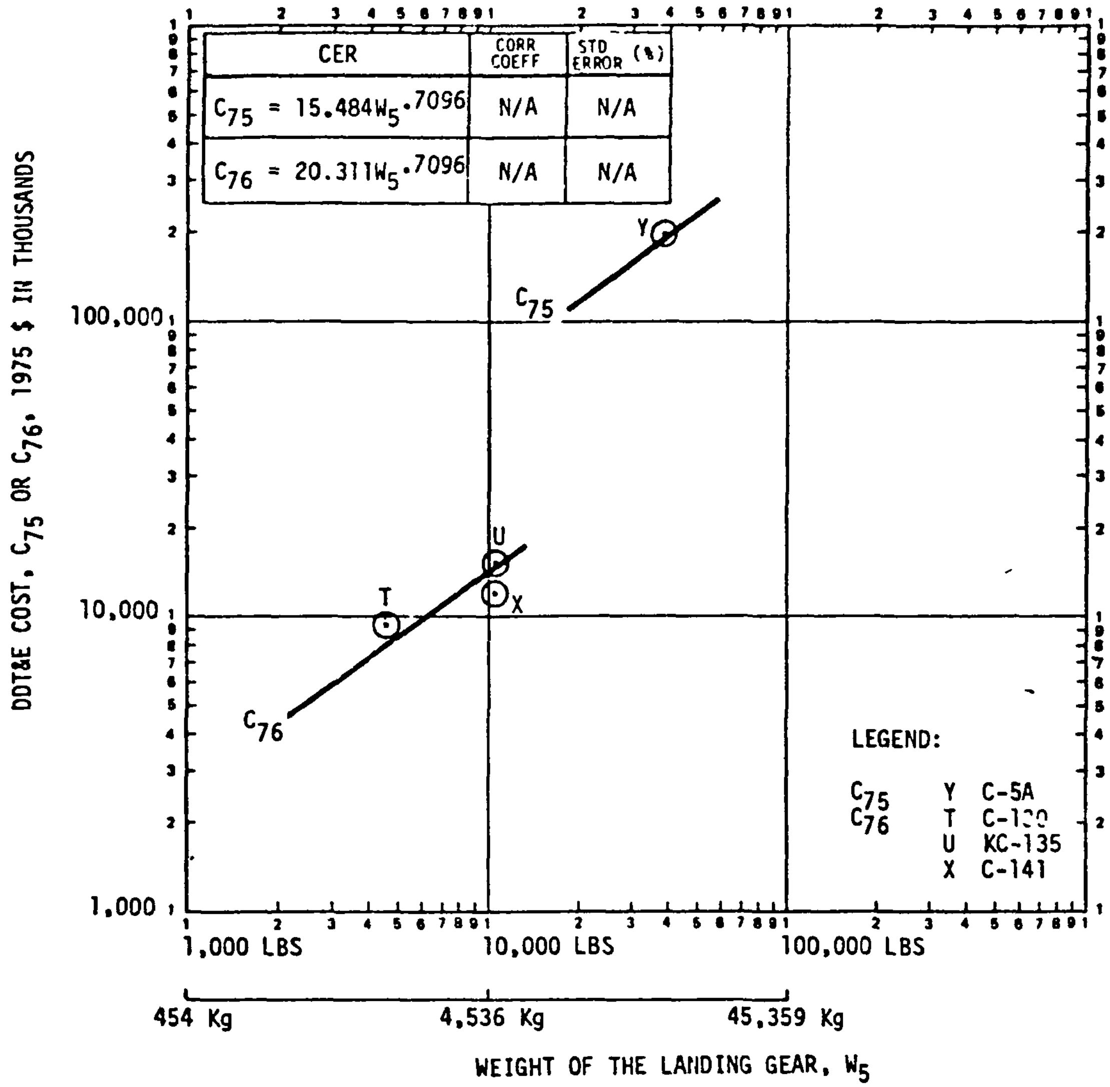


FIGURE X-D-36

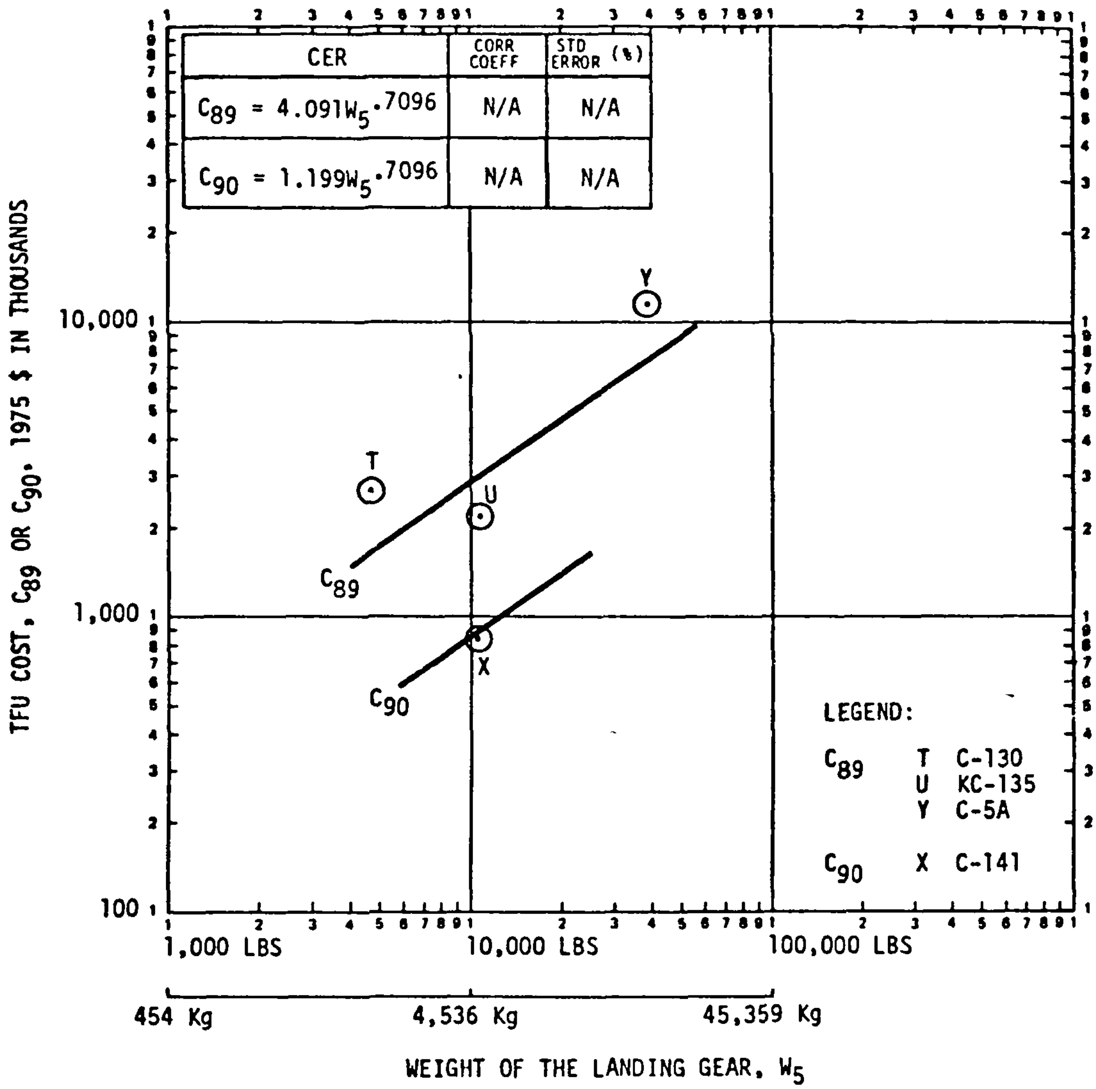
STRUCTURAL FRAMEWORK



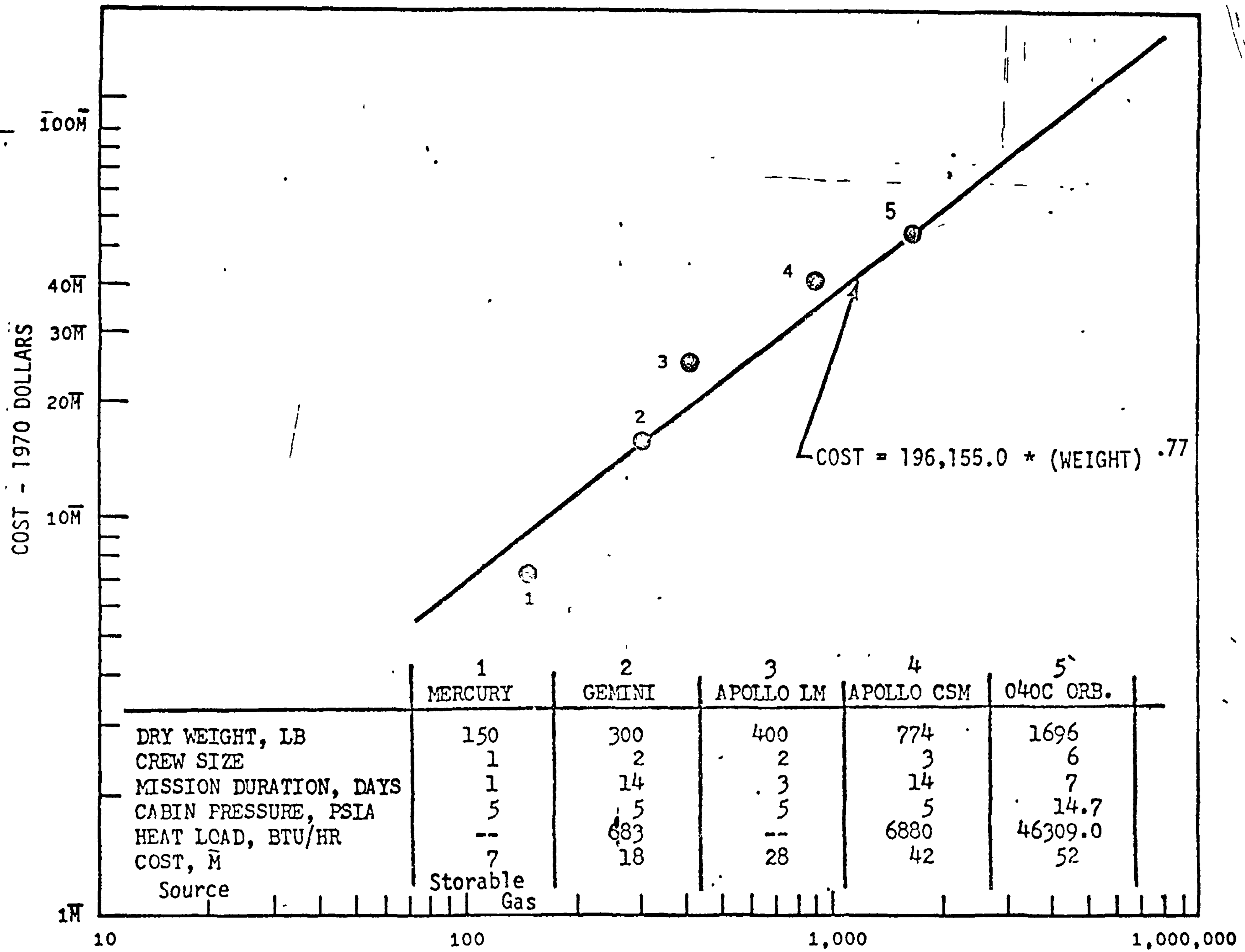
LANDING GEAR



LANDING GEAR



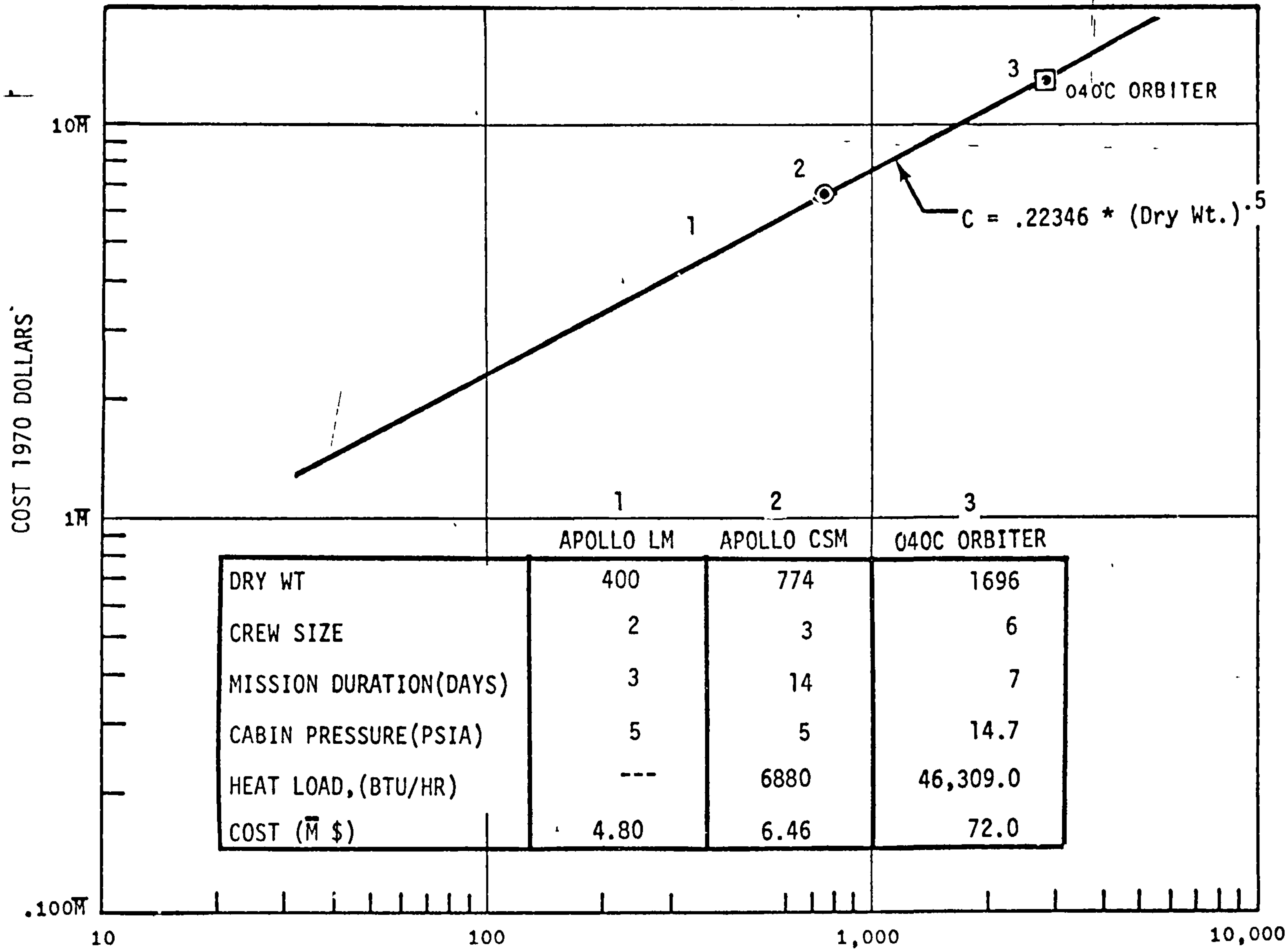
CER	CORR COEFF	STD ERROR (%)
$C_{89} = 4.091W_5^{.7096}$	N/A	N/A
$C_{90} = 1.199W_5^{.7096}$	N/A	N/A



	1 MERCURY	2 GEMINI	3 APOLLO LM	4 APOLLO CSM	5 040C ORB.
DRY WEIGHT, LB	150	300	400	774	1696
CREW SIZE	1	2	2	3	6
MISSION DURATION, DAYS	1	14	3	14	7
CABIN PRESSURE, PSIA	5	5	5	5	14.7
HEAT LOAD, BTU/HR	--	683	--	6880	46309.0
COST, M̄	7	18	28	42	52
Source	Storable Gas				

FIGURE X-D-39 FCS D&D CER

1.3.5 ENVIRONMENTAL CONTROL SUBCONTRACT TFU COST



	1 APOLLO LM	2 APOLLO CSM	3 040C ORBITER
DRY WT	400	774	1696
CREW SIZE	2	3	6
MISSION DURATION(DAYS)	3	14	7
CABIN PRESSURE(PSIA)	5	5	14.7
HEAT LOAD,(BTU/HR)	---	6880	46,309.0
COST ($\overline{M}$ $)	4.80	6.46	72.0

FIGURE X-D-40 ECS TFU CER

DDT&E

Structural Framework	65 M (75 $'s)
Landing Gear	6 M (75 $'s)
ECS	13 M (70 $'s)

TFU

Structural Framework	6 M (75 $'s)
Landing Gear	1 M (75 $'s)
ECS	3 M (70 $'s)

Escalation to 1977 dollars results in the following estimate:

DDT&E	109 M
TFU	16 M

1.3.2.3 Solar Cell Blanket

Development of the Solar Cell Blanket Installer will be somewhat more complex than development of the Reflector Installer. Because the two systems, both of which weigh 22,000 lbs., are alike in many respects, however, common development would result in a substantial cost saving. Therefore, it is assumed that development costs for the Solar Cell Blanket Installer would be the same as for the Reflector Installer.

DDT&E	110 M
TFU	16 M

1.3.2.4 Conductor Installer

The Conductor Installer uses a manipulator system much like the Shuttle RMS. It will also require mechanical/hydraulic transporter devices. For costing purposes it is assumed that this system is similar in function and complexity to a composite of the following:

Shuttle Orbiter RMS	70%
Landing Gear	30%

The total weight of the installer is 11,000 lbs. Using the scaling factors described under WBS 1.3.1., General Costing Methodology, and the PRC Landing Gear CER, the cost of the installer may be estimated as shown below:

DDT&E

Shuttle RMS: $\left(\frac{7700}{965}\right)^{.5} \times (75) = 213$ M (1977 $'s)

Landing Gear: 6 M (1975 $'s)

TFU

Shuttle RMS: $\left(\frac{7700}{965}\right)^{.75}$ X (5) = 24 (1977 $'s)

Landing Gear: 1 (1975 $'s)

Escalation to 1977 dollars results in the following estimates:

DDT&E	221 M
TFU	25 M

1.3.2.5 Mobile Manipulator

The Mobile Manipulator will be similar to the system described above (1.3.2.4), except that it will be manned. Thus, it is assumed that this system is similar to a composite of the following:

Shuttle Orbiter RMS
Gemini ECS

Total weight of the system is 11,000 lbs. Using the scaling factors described above and using Gemini ECS costs as a throughput, the following cost estimate may be derived:

DDT&E

Shuttle RMS $\left(\frac{11000}{965}\right)^{.5}$ X 75 = 255 M (1977 $'s)
Gemini ECS = 7 M (1970 $'s)

TFU

Shuttle RMS $\left(\frac{11000}{965}\right)^{.75}$ X 5 = 31 M (1977 $'s)
Gemini ECS = 2 M (1970 $'s)

Escalation to 1977 dollars results in the following:

DDT&E	267 M
TFU	34 M

1.3.2.6 Docking Module

Docking Modules will be used to join major sections of the SPS. This system will be similar in function and complexity to a composite of the following:

Docking Mechanism	10 %
Landing Gear	10 %
Stabilization and Control	1 %
Structural Framework	79 %

Costs for the Docking Mechanism were scaled up from the Rockwell Phase B Space Station cost estimate according to previously described scaling assumption. Landing Gear and Structural Framework are based on the PRC CER's. Stabilization and Control costs are derived from a Rockwell Phase B Space Station CER (fig. X-D-41 & 42). The total weight of the system is 11,000 lbs.

DDT&E

Docking Mechanism	$\left(\frac{1100}{580}\right)^{.5} \times (39.5)$	= 54 M
Landing Gear		= 3 M
Stabilization & Control		= 29 M
Structural Framework		= 42 M

TFU

Docking Mechanism	$\left(\frac{1100}{580}\right)^{.5} \times (6)$	= 10 M (1970 $'s)
Landing Gear		= 1 M (1975 $'s)
Stabilization and Control		= 3 M (1970 $'s)
Structural Framework		= 4 M (1975 $'s)

Escalation to 1977 dollars results in the following cost estimate:

DDT&E	205 M
TFU	28 M

1.3.3 Antenna Fabrication & Assembly

1.3.3.1. Antenna Beam Builder

The Antenna Beam Builder is functionally similar to the larger Solar Collector Beam Builder (WBS 1.3.2.1). Because they are so much alike, the costing assumptions for the larger beam builder are used here, also.

a. Structural Framework 43 %
b. Landing Gear 40 %
c. ECS 15 %
d. Displays & Controls 2 %

Applying the previously selected CER's (WBS 1.3.2.1) to a total system weight of 2200 lbs yields the following:

DDT&E

Structural Framework	12 (1975 $'s)
Landing Gear	3 (1975 $'s)
ECS	17 (1970 $'s)
Displays & Controls	3 (1977 $'s)

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FIGURE X-D-41
STABILIZATION & CONTROL SYSTEM
DDT & E COST 1970 $ IN MILLIONS

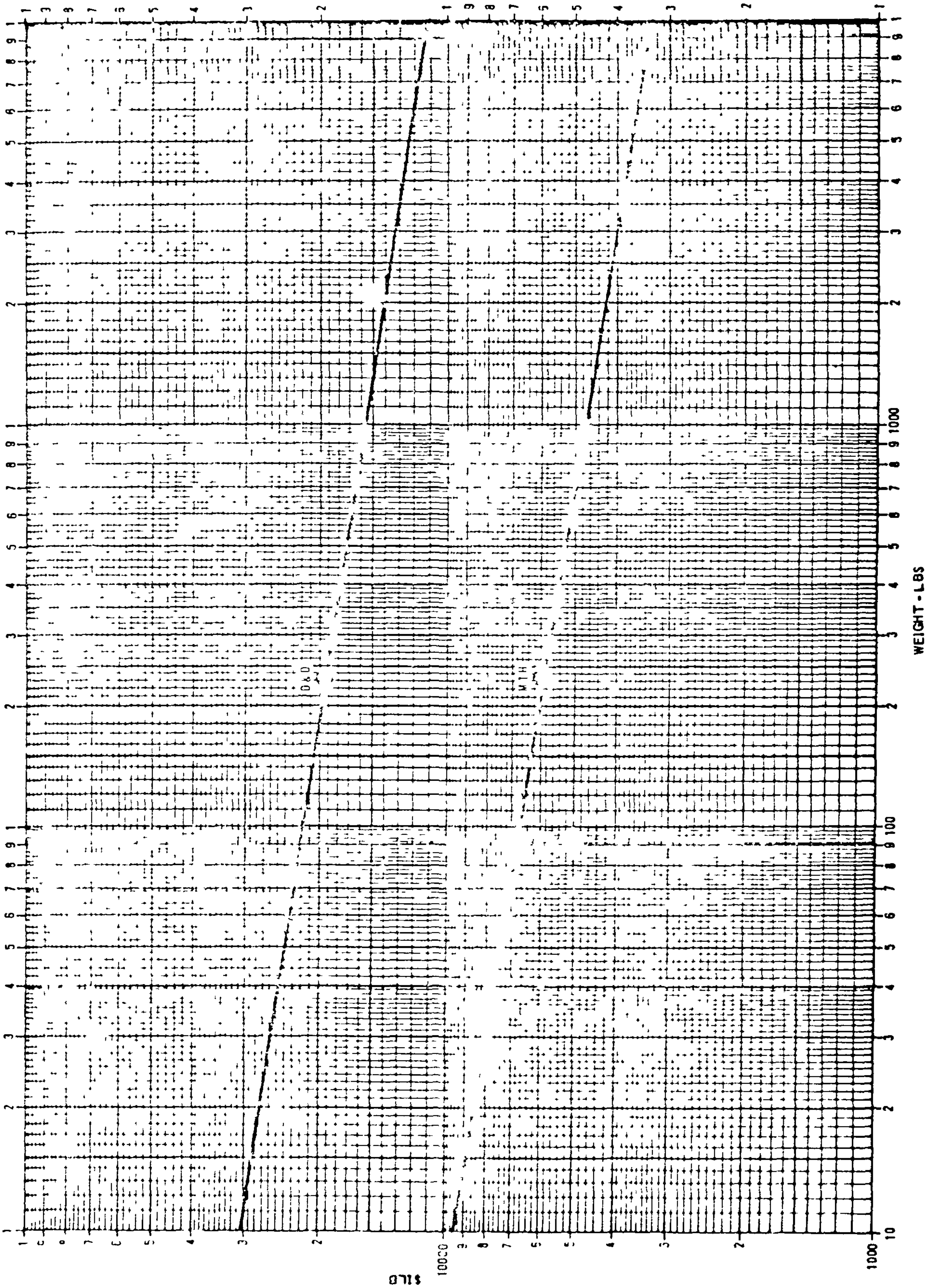

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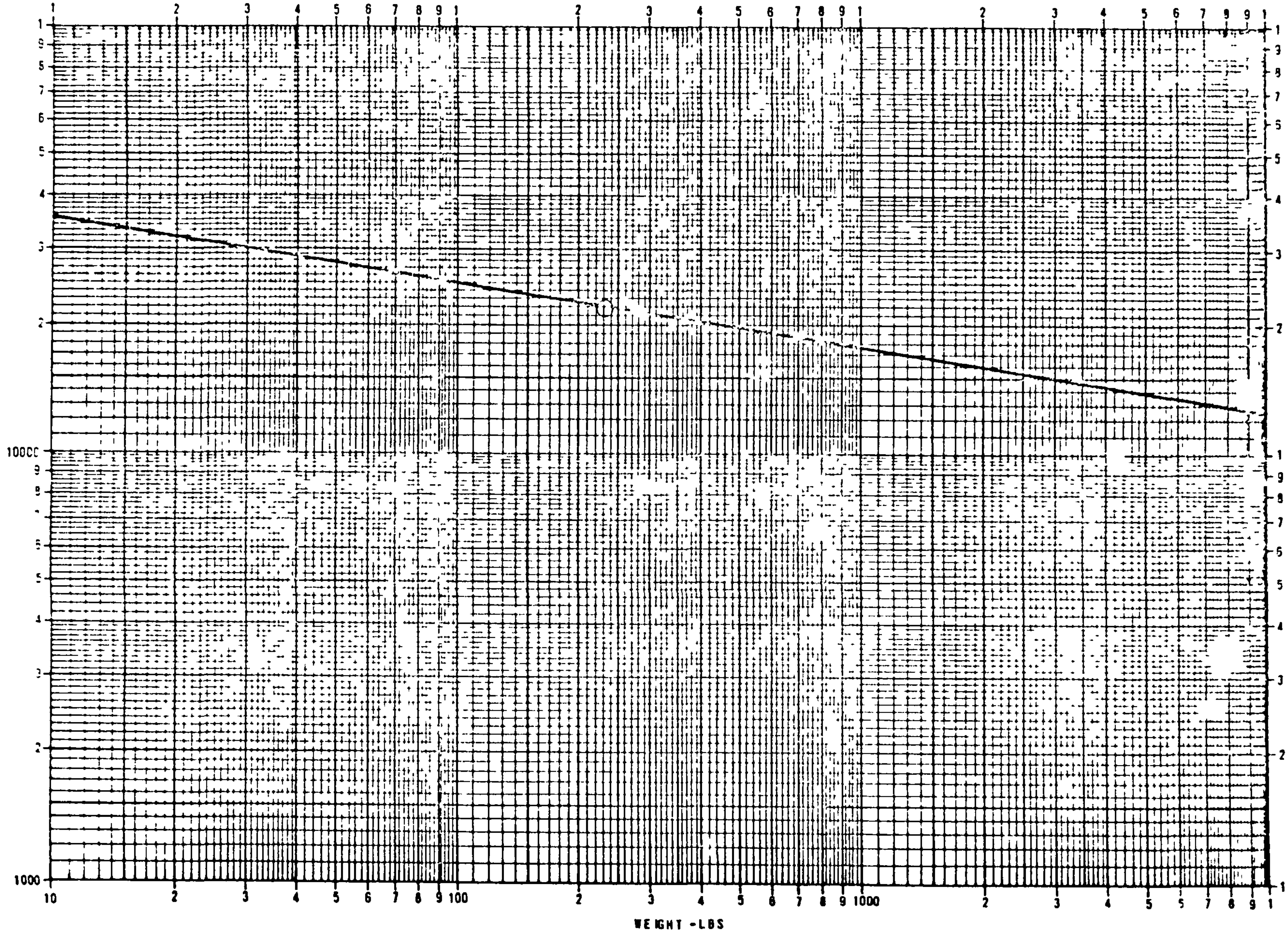
FIGURE X-D-42
STABILIZATION AND CONTROL SYSTEM
TFV COST 1970 $



TFU

Structural Framework	1 (1975 $'s)
Landing Gear	1 (1975 $'s)
ECS	4 (1970 $'s)
Displays & Controls	3 (1977 $'s)

Escalated to 1977 dollars:

DDT&E	$51 M
TFU	$12 M

1.3.3.2 Antenna Conductor Installer

Like the Solar Collector Conductor Installer, the Antenna Conductor Installer will closely resemble the Shuttle RMS mated to a transporter device. System costs are based on cost/weight relationships for the following:

Shuttle Orbiter RMS	70 %
Landing Gear	30 %

Applying previously discussed scaling factors to Shuttle RMS costs, and the PRC Cost Estimating Relationship for Landing Gear, system costs are as follows:

DDT&E

Shuttle RMS: $\left(\frac{7700}{965}\right)^{.5} \times (75) = 213$ M (1977 $'s)

Landing Gear: $= 6$ M (1975 $'s)

TFU

Shuttle RMS: $\left(\frac{7700}{965}\right)^{.5} \times (5) = 24$ M (1977 $'s)

Landing Gear: $= 1$ M (1975 $'s)

Assuming common development with the Solar Collector Conductor Installer, a DDT&E cost saving of fifty percent for the Antenna Conductor Installer should be achievable.

Escalation of these estimates to 1977 dollars yields the following:

DDT&E	110 M
TFU	25 M

1.3.3.3 Antenna Subarray Installer

The Antenna Subarray Installer will resemble a manipulator device with additional mobility provided by transporters. The following systems approximate its function and complexity.

Shuttle Orbiter RMS	20 %
Structural Framework	65 %
Landing Gear	15 %

Applying appropriate estimating relationships and scaling factors to a total weight of 11000 lbs results in the following:

DDT&E

Shuttle RMS	$\left(\frac{2200}{965}\right)^{.5}$	X	(75)	=	113 M (1977 $'s)
Structural Framework				=	38 M (1975 $'s)
Landing Gear					4 M (1975 $'s)

TFU

Shuttle RMS	$\left(\frac{2200}{965}\right)^{.75}$	X	(5)	=	9 M (1977 $'s)
Structural Framework				=	3 M (1975 $'s)
Landing Gear				=	1 M (1975 $'s)

Escalation to 1977 dollars yields the following cost estimate:

DDT&E	165 M
TFU	14 M

WBS 1.3.2 & 1.3.3

COST SUMMARY

COST SUMMARY
WBS 1.3.2 SPS SOLAR COLLECTOR FABRICATION & ASSEMBLY
MILLIONS 1977 DOLLARS

WBS	DESCRIPTION	NON-RECURRING	UNITS	RECURRING TFU	RECURRING PRODUCTION	OPERATIONS	TOTAL
1.3.2	SATELLITE FAB & ASS'Y PROJ'T	1310		222	5159	2445	8914
1.3.2.1	BEAM BUILDER	202	105	43	2682	1316	4200
1.3.2.1.1	BASIC HARDWARE	162		29	1757		1919
1.3.2.1.2	SPARES	-		4	264	1316	1580
1.3.2.1.3	IA & CO	7		4	273		280
1.3.2.1.4	SYSTEM TEST	5		1	68		73
1.3.2.1.5	GSE	7		2	95		102
1.3.2.1.6	SE & I	13		3	172		185
1.3.2.1.7	PROGRAM MGT	8		1	53		61
1.3.2.2	REFLECTOR INSTALLER	133	14	24	265	121	519
1.3.2.2.1	BASIC HARDWARE	109		16	172		281
1.3.2.2.2	SPARES	-		2	22	121	143
1.3.2.2.3	IA & CO	3		2	22		25
1.3.2.2.4	SYSTEM TEST	3		1	11		14
1.3.2.2.5	GSE	5		1	11		16
1.3.2.2.6	SE & I	8		2	22		30
1.3.2.2.7	PROGRAM MGT	5		-	5		10
1.3.2.3	SOLAR BLANKET INSTALLER	135	7	24	145	67	347
1.3.2.3.1	BASIC HARDWARE	110		16	94		204
1.3.2.3.2	SPARES	-		2	12	67	79
1.3.2.3.3	IA & CO	4		2	12		16
1.3.2.3.4	SYSTEM TEST	3		1	6		9
1.3.2.3.5	GSE	5		1	6		11
1.3.2.3.6	SE & I	8		2	12		20
1.3.2.3.7	PROGRAM MGT	5		-	3		8

COST SUMMARY
W.B.S. 1.3.2 SPS SOLAR COLLECTOR FAB & ASSEMBLY
MILLIONS 1977 DOLLARS

WBS	DESCRIPTION	NON-RECURRING	UNITS	RECURRING TFU	RECURRING PRODUCTION	OPERATIONS	TOTAL
1.3.2.4	CONDUCTOR INSTALLER	267	14	38	409	184	860
1.3.2.4.1	BASIC HARDWARE	221		25	269		490
1.3.2.4.2	SPARES	-		4	43	184	227
1.3.2.4.3	IA & CO	3		4	43		46
1.3.2.4.4	SYSTEM TEST	7		1	11		18
1.3.2.4.5	GSE	9		1	11		20
1.3.2.4.6	SE & I	17		2	21		38
1.3.2.4.7	PROGRAM MGT	10		1	11		21
1.3.2.5	MOBILE MANIPULATOR	321	35	51	1207	552	2080
1.3.2.5.1	BASIC HARDWARE	267		34	805		1072
1.3.2.5.2	SPARES	-		5	118	552	670
1.3.2.5.3	IA & CO	8		5	118		126
1.3.2.5.4	SYSTEM TEST	8		1	24		32
1.3.2.5.5	CSE	11		2	47		58
1.3.2.5.6	SE & I	21		3	71		92
1.3.2.5.7							
1.3.2.6	DOCKING MODULE	252	14	42	451	205	908
1.3.2.6.1	BASIC HARDWARE	205		28	300		505
1.3.2.6.2	SPARES	-		4	43	205	248
1.3.2.6.3	IA & CO	6		4	43		49
1.3.2.6.4	SYSTEM TEST	6		1	11		17
1.3.2.6.5	GSE	9		1	11		20
1.3.2.6.6	SE & I	16		3	32		48
1.3.2.6.7	PROGRAM MGT	10		1	11		21

COST SUMMARY
W.B.S. 1.3.3 SPS ANTENNA FABRICATION & ASSEMBLY
MILLIONS 1977 DOLLARS

WBS	DESCRIPTION	NON-RECURRING	UNITS	RECURRING TFU	RECURRING PRODUCTION	OPERATIONS	TOTAL
1.3.3	ANTENNA FAB & ASS'Y PROJ'T	403		77	2498	1101	4002
1.3.3.1	ANTENNA BEAM BUILDER	64	126	18	1336	571	1971
1.3.3.1.1	BASIC HARDWARE	51		12	850		901
1.3.3.1.2	SPARES	-		2	142	571	713
1.3.3.1.3	IA & CO	3		2	142		145
1.3.3.1.4	SYSTEM TEST	2		-	34		36
1.3.3.1.5	GSE	2		1	71		73
1.3.3.1.6	SE & I	4		1	71		75
1.3.3.1.7	PROGRAM MGT	2		-	26		28
1.3.3.2	ANTENNA CONDUCTOR INSTAL-LER	138	28	38	743	334	1215
1.3.3.2.1	BASIC HARDWARE	110		25	488		598
1.3.3.2.2	SPARES	-		4	78	334	412
1.3.3.2.3	IA & CO	6		4	78		84
1.3.3.2.4	SYSTEM TEST	3		1	20		23
1.3.3.2.5	GSE	5		1	20		25
1.3.3.2.6	SE & I	9		2	39		48
1.3.3.2.7	PROGRAM MGT	5		1	20		25
1.3.3.3	ANTENNA SUBARRAY INSTAL-LER	201	28	21	419	196	816
1.3.3.3.1	BASIC HARDWARE	165		14	273		438
1.3.3.3.2	SPARES	-		2	39	196	235
1.3.3.3.3	IA & CO	3		2	39		42
1.3.3.3.4	SYSTEM TEST	5		1	20		25
1.3.3.3.5	GSE	7		1	20		27
1.3.3.3.6	SE & I	13		1	20		33
1.3.3.3.7	PROGRAM MGT	8		-	8		16

COST SUMMARY
WBS 1.3.4 SPS FABRICATION & ASSEMBLY SUPPORT
MILLIONS 1977 DOLLARS

WBS	DESCRIPTION	NON-RECURRING	UNITS	TFU	PRODUCTION	OPERATIONS	TOTAL
1.3.4	FAB & ASSEMBLY SUPPORT					1659	1659
1.3.4.1	PROJECT MGT					496	496
1.3.4.2	SUSTAINING ENGRG					496	496
1.3.4.3	ANOMALY RESOLUTION					496	496
1.3.4.4	GROUND SYSTEMS SPT					155	155
1.3.4.5	GROUND LOGISTICS					16	16

SAMPLE CALCULATIONS

1.3.2.1 Beam Builder

The Solar Collector Beam Builder will be made up of subsystems characterized by mechanical and hydraulic control surfaces, thermal control devices, monitoring and control instrumentation, and a variety of structural elements. During discussions with E&D engineers, it was jointly dtermined that the Beam Builder would be analogous to a weighted composite of the aerospace subsystems listed below.

Structural Framework	(43 %)
Landing Gear	(40 %)
Environmental Control (ECS)	(15 %)
Displays & Controls	(2 %)

Cost Estimating Relationships (CER's) were used to estimate the cost of structural Framework, Landing Gear, and ECS. CER's selected for Structural Framework (figures X-D-35 & 36) and Landing Gear (Figures X-D-37 & 38) were derived under contract to NASA (NAS 1-13869) by Planning Research Corporation (PRC) of Huntsville, Alabama. The CER selected for estimating ECS costs was developed by JSC for the Shuttle 040C Agency Commitment Estimate (figures X-D-39 & 40).

DDT&E

a. The curve derived by PRC for costing Structural Framework (figure 2) is defined by the equation

$$C = 234.351\ W^{.572}$$

The weight of the Beam Builder is approximately 5000 KG (11000 lb). Fourty-three percent, or 4730 lb, must be applied to the Structural Framework.

$$C = 234.351\ (4730)^{.572}$$

$= 234.351\ (126.48)$
$= \$30\ M\ (1975\ dollars)$

b. Fourty percent, or 4400 lb, of the Beam Builder must be applied to the Landing Gear CER.

$$C = 20.311W^{.7096}$$
$$= 20.311\ (4400)^{.7096}$$
$$= 20.311\ (385)$$
$$= \$8\ M\ (1975\ Dollars)$$

c. Fifteen percent, or 1650 lb, of the Beam Builder is analogous to ECS. The selected CER (figure X-D-39) is defined by the curve

$$C = 196155W^{.77}$$
$$= 196155\ (1650)^{.77}$$
$$= 196155\ (300)$$
$$= \$59\ M\ (1970\ Dollars)$$

d. The Displays and Controls estimate was generated by the RCA PRICE Model. PRICE generates cost estimates based on physical and programmatic parameters that are closely related to design complexity and other factors bearing on cost.

Assuming a weight of 220 lb, the Price-generated estimate for Displays and Controls in \$9 M.

TFU

TFU costs were generated in a manner very similar to that described above for DDT&E.

a. The curve derived by PRC for Structural Framework (figure X-D-36) is

$$C = 8.097W^{.676}$$

Sugstituting the appropriate weight factor of 4730 lb,

$$C = 8.097\ (4730)\ .676$$
$$= 8.097\ (305)$$
$$= 2.47\ M\ (1975\ Dollars)$$

b. The TFU CER for Landing Gear is

$$C = 4.09W^{.7096}$$

Substituting 4400 for "W"

$$C = 4.091\ (4400)^{.7096}$$
$$= 4.091\ (385)$$
$$= 1.6\ M\ (1975\ dollars)$$

c. The TFU CER FOR ECS IS

$$C= .22346W^{.5}$$

Substituting a weight of 1650 lb,

$$C= .22346\ (1650)^{.5}$$
$$= .22346\ (40)$$
$$= \$9\ M\ (1970\ \text{dollars})$$

d. Assuming a subsystem weight of 220 lb, the RCA Price-generated TFU estimate for displays and controls is $9 M.

Following escalation to 1977 dollars, Beam Builder costs may be summarized as follows

	DDT&E	TFU
Structural Framework	$38 M	$2 M
Landing Gear	10	2
ECS	105	16
Displays & Controls	9	9
Total	$162 M	$29 M

WBS 1.4.1 Facilities

Methodology:

Individual methods for all sub-level WBS's are shown in succeeding pages.

Conclusion & Comments:

Methods chosen were to provide order-of magnitude facility costs. No detailed facility plans were available. The launch scenario called for up to 4000 HLLV launches per year, and this is a major sizing factor.

Most data are based on Saturn V and Space Shuttle Facilities. However, little data were available for liquid hydrogen production facilities, and the estimates herein are scaled from a single point of data.

Many of the estimates are highly concept dependent (e.g., processing facilities) and many are not (e.g., runways). In fact there is a class of estimates which is so highly concept and location dependent as to be virtually impossible to estimate without a detailed basing plan. Some of these are:

Launch Control Center
Downrange processing facility
Payload handling facilities
Utility hookups
New Railroad Roadbeds
Roads
Water provisions

Rough order of magnitude estimates for these items would indicate that they are no more than 2-5% of the total however, so no major error should be introduced by these uncertainties, unless, for example, the availability of water in desert areas were to become a driving factor.

In summary, this is a good planning estimate, but has some major weaknesses.

WBS 1.4.1.1 Launch Pads

Methodology:

Costs are based on the cost of complex 39, escalated to 1977 dollars, learned at 90% for 6 pads. A circular (hexagonal) patterm is assumed, ten miles in diameter, with the processing facility at the center. Actual aerospace escalation model used.

Input Data

(See general assumptions)
Schedule: 3 years

Summary of Results (All costs in millions of 1977 dollars)

Unit Cost: $97.2M (1st of 6)

Conclusions

Although the complex 39 analogy was the best available, the designs for high-launch rate pads would undoubtedly be different from complex 39.

The costs are felt to be realistic (± 30%).

WBS 1.4.1.2 Mobile Launch Platforms

Methodology & Input Data

Costs are based on the cost of Saturn V Mobile Launch platforms. One platform for every active launch vehicle (70 vehicles X .8 incommission rate = 56 platforms). 90% learning was assumed, as well as a 3 year construction schedule for each platform. Size differences between Saturn V and HLLV platforms were ingnored, but would probably not create major errors. Buys were assumed to be spread over a 20 year time span to reduce peak funding. Thus, the design is very likely to evolve from early to later models crawler costs are included (pro rata).

Summary of Results

Unit Cost: 60.75M (1st of 56)

Conclusions:

Analogy considered good if this concept is adopted.

WBS 1.4.1.3 Mobile Service Structure

Methodology & Input Data

As in the case of the mobile launch platform, costs are based on Saturn V Service Structure costs. However, it is assumed that a total of eight structures would suffice (one for each pad plus two spares). Costs were escalated to 1977 dollars and learned at 90%.

Summary of Results

Unit Cost: 48.6 (1st of 8)

Conclusions

The analogy is considered very good (Costs ± 10%), if this launch concept is used. Cost not as concept - dependent as others in this section.

WBS 1.4.1.4 Crawler Ways

Methodology & Input Data

The ten mile diameter complex described in 1.4.1.1 was assumed, with crawler ways to each pad from central processing facilities. Complex 39 way costs per mile, multiplied by the required 30 miles of ways, were escalated to 1977 dollars. No learning was assumed.

Summary of Results

Cost Per Mile: 4.86 M (X 30 mi)
Total Cost: 145.8 M

Conclusions

This analogy is considered to be very good, because any site location being considered is likely to have stable, sandy soil, perhaps more stable than KSC. Costs could conceivably be high for this reason.

Costs are very dependent on the concept chosen.

WBS 1.4.1.5 Runways

Methodology & Input Data

Runway costs were based on Shuttle Runway costs, escalated to 1977 dollars. Only a minimum of facilities is costed at the downrange runway site (safing and railway loading).

Summary of Results

Cost (Each): 35 M
Cost (2): 70 M

Conclusions

The analogy is felt to be exact (±5%).

WBS 1.4.1.6 Land

Methodology & Input Data

The circular launch site (11 miles in diameter to the outer perimeter) is assumed. This amounts to 100 square miles or 64,000 acres. Land price was assumed to be $400 per acre (desert land). The recovery site was assumed to be 20,000 acres.

Results

Cost: Launch: 64,000 acres @ $400 = 25.6 M
Recovery: 20,000 acres @ $400 = 8.0 M

Conclusions

The costs are accurate if the assumed facility concept is adopted, and desert land is employed.

WBS 1.4.1.7 Service Facilities

Methodology & Input Data

This is one of the largest items in the estimate. Costs are based on the KSC VAB and stage preparation facilities, including all cranes, handling equipment, buildings, office space, shops, utilities, etc. A launch rate of 10 per day, with 56 vehicles in flow for 6 days each will require a 56 bay facility, or roughly 9 to 10 times the VAB facilities. The VAB cost was raised by this ratio and escalated to 1977 dollars.

Results

Facility costs: 3914.4

Conclusions

Although the HLLV is physically larger than the Saturn V, the number of subsystems is basically the same, and the number of stages is less (2 vs 3). These two effects are assumed to offset. It was assummed that vehicles will be erected outdoors, thus no indoor space is needed for 56 vehicles in the erect position.

Costs are considered to be only rough order of magnitude ($\pm$50%).

WBS 1.4.1.8 Railroad Spurs, Marshalling Yards, Warehouses

Methodology & Input Data

Railroads cost about 40¢ per foot, including grade preparation, in areas of stable soil. ($2112 per mile). This cost can increase by orders of magnitude in mountainous terrain.

This estimate was prepared as follows:

Warehouses: 1M ft^2 @ $\$30/\text{ft}^2$ =	$30 M
Railroads: 50 mi @ 2112 =	.1
Terminals, etc	1.0
Payload receiving facility	9.0
	40.1 M

The use of commercial rail lines for transportation from recovery site to launch site is assumed.

Results

Total Cost 40.1 M

Conclusions

Warehouses are highly dependent on the operational concept, and may be undersized. Since some of the facility might be in mountainous terrain, railroad costs may be considerably understated; However, fifty miles should be an adequate allowance for marshalling yard connections, etc. Costs are highly dependent on concept chosen, and could be low by factors of 3-5.

WBS 1.4.1.9 Fuel Pipeline Connections

Methodology of Input Data

This estimate was based on a non-cryogenic pipeline of $2 per foot for 350 mi, plus terminal costs of $300 K.

Results:

Cost:	Pipeline	3.7 M
	Terminal	0.3 M
		4.0 M

Conclusions:

Pipeline costs are not verified; no data was in hand on propane pipelines, and chemical line costs were used. However, these costs should be a small percentage of total facility costs.

WBS 1.4.1.10 Propane Liquification Plant

Methodology:

This was an assumed number (ROM).

Results:

Total Cost: 2 plants @ 50 M = 100 M

Conclusions

This cost must be verified, and could be in error by an order of magnitude.

WBS 1.4.1.11 Hydrogen Plant

Methodology:

Cost data for large cryogenic hydrogen plants, of the scale rquired here, is scarce. The Shuttle hydrogen facility, designed to produce 30 tons of LH_2 per day, will cost approximately $90 M. Scaling this with the customary fabrication scaling exponent results in the following CER:

$$C = 11.694\ W^{.69}$$

Where W is production in tons per day and C is the total plant cost in millions of 1977 dollars.

A capacity of 17,534 tons per day, that required to support scenario B (hydrogen fueled orbiter, propane booster) was assumed to be required by 2025.

Results

$$C = 11.694\ (17534)^{0.6} = \$4.114\ B$$

A cost of 4.0 billion was assumed

Conclusions

The magnitude of this cost indicates the need for much greater study in this area. Cost fidelity is considered to be low, but the estimate is probably conservatively high.

WBS 1.4.1.90 Program Management & Integration

Methodology:

A 20% factor was applied to all estimates for program Management & Integration.

Results:

$$C = 0.2 \times 11{,}278$$
$$C = 2255.6\ M$$

Conclusions

This method represents data from large NASA R&D programs, and is adequate for planning purposes.

Assumptions

1. WSTF study ops concept

2. NASA costs include

   - Launch site facility development
   - Landing site facility development
   - Tow path preparation costs
   - Transporters
   - Fuel facility
   - Pipeline, tie-in only

3. 70 Vehicle fleet size

4. 12 hours pad time per launch

5. Traffic Model: Peak launch rate 4000 per year in 2024

- YR	LAUNCH RATE		PADS
1995	200		1
2000	600		1
2005	1200		2
2010	2000		3
2015	3000		5
2020	3500	10/day peak	6
2025	4000	11/day peak	6
2030	100		

6. 6 day turnaround per vehicle

7. 6 pads required (4000 730)

8. Mobile Service Structures 12 hrs use per launch + 2 Standby = 6 + 2 = 8

9. Raw Land Cost $ 400 / Acre

10. Use of Existing Rail Facilities for return of empty boosters; minimal facilities at recovery site.

11. Time Spreads

	UNIT	TOTAL
PADS	3 yrs	
MLP	4 yrs	2 groups of 8 years
MSS	3 yrs	
WAYS	2 yrs	
RUNWAYS	2 yrs	

Assumptions cont.

	UNIT	TOTAL
LAND	1 yrs	
SERVICE FACILITY	5 yrs	
RR's	2 yrs	
PIPELINES	1 yrs	
PROPANE/LOX PLANTS	3 yrs	
HYDROGEN PLANT	23 yrs	

12. Operational Readiness Date is 1995 for HLLV

13. Service Facility (Buildings, cranes, equipment)

    Based on VAB cost @ 177.8 ($1966)
    VAB will service 6 vehicles (30M/Vehicle)
    56 vehicles @ $30 M = $1680M

14. Railroad costs:

    5280 ^{ft}/ mi X $.40/ft = $2112/mi
    Source: Constructon Industry Standards for preparation of roadbed on stabilized earth and laying track

15. Hydrogen Plant Costs

    Hydrogen Plant CER:

    Based on a cost of $90M for a 30 TON PER DAY PLANT:

    $C = 11.694W^{.60}$
    C = Cost in $ Millions 1977
    W = Tons per day liquid hydrogen

    Source: Shuttle Facilities Office, NASA Hqs.

    Tonnage Required (Second Stage Only)

	FLTS/YR	TONS/FLT	TONS/DAY	T/DAY
95	200	1600	877	
2000	600	1600	2630	1753
05	1200	1600	5260	2630
10	2000	1600	8767	3457
15	3000	1600	13150	4383
20	3500	1600	15342	2192
25	4000	1600	17534	2192

Cost of Total Capacity (17,534 TONS/DAY)

$C = 4.114$ B (ASSUME 4.0 $\overline{B}$)

Assume Single Plant

- Initial Capacity = 877 T/Day ($700M)
- Linear Additions over 20 years to 4.00 B (77 $) @ 165M/YR

WBS 1.4.1 FACILITIES

COST ESTIMATE

ITEM	QTY	UNIT COST	LEARNING	YEAR $	TOTALS 77$
1.4.1.1					
PADS	6	40M	90%	65	495.7
1.4.1.2					
MLP	56	25M	90%	65	2151.8
1.4.1.3					
MOBILE SERV. STR.	8 peak	20M	90	65	319.3
1.4.1.4					
CRAWLER WAYS	30 miles	2M/mile	100	65	145.8
1.4.1.5					
RUNWAYS	2	30M	100	75	69.6
1.4.1.6					
LAND					
LAUNCH	64,000 Acres	.000	100	77	25.6
RECOVERY	20,000 Acres	.000	100	77	8.0
1.4.1.7					
SERVICE FACILITY	1	1680	100	66	3914.4
1.4.1.8					
RAILROAD SPURS MARSHALLING YARD WAREHOUSES	1	40	100	77	40.0
1.4.1.9					
FUEL PIPELINE CONNECTIONS	2	4	100	77	8.0
1.4.1.10					
PROPANE LIQUIFICATION PLANT		50	100	77	100.0

ITEM	QTY	UNIT COST	LEARNING	YEAR $	TOTALS 77 $
1.4.1.11					
HYDROGEN PLANT	1	-	100	77	4000.0
					11,278.2
1.4.1.90					
PROGRAM MGT. & INTEGRATION @ 1.2					2255.6
			GRAND TOTAL		$13,533.8 $\overline{M}$

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WBS 1.4.1 FACILTY COST PHASING

	90	91	92	93	94	95	96	97	98	99	2000	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
PADS				20	55	22								18	49	20			17	46	19	18	44	18	18	43	17	18	42	17							495
MLP			23	104	197	257	280	206	113	27												18	85	180	209	211	187	92	22								2150
MOBILE SERV STR			10	27	11	10						23	9	9	21	9	8	20	8	8																	318
				9	25						9	8	22	8	8	21	8	7	20																		
CRAWLER WAYS				72	74																																146
RUNWAYS				34	36																																70
LAND			34																																		34
SERVICE FACIL	239	986	1386	1030	274																																3915
RR SPURS				40																																	40
FUEL PIPELINES					4																		4														8
PROPANE LIQ PLANT			22	56	22																																100
HYDROGEN PLANT		100	200	300	265	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	90	75												4000
SUBTOTAL	239	1086	1675	1692	963	454	425	370	276	192	174	196	196	200	243	215	181	192	210	219	184	199	296	268	300	254	184	108	84	17							11276
PROG MGT & INTEGR	48	217	335	338	193	91	85	74	56	38	35	39	39	40	49	43	36	38	42	44	37	40	90	54	60	51	37	22	13	3							2257
GRAND TOTAL	287	1303	2010	2030	1156	545	510	444	334	230	209	235	235	240	292	258	217	230	252	263	221	239	358	322	360	305	221	130	77	20							13533

15. Hydrogen Plant Costs

Hydrogen Plant CER:

Based on a cost of $90M for a 30 TON PER DAY PLANT:

$$C = 11.694W^{.60}$$

C = Cost in $ Millions 1977

W = Tons per day liquid hydrogen

Source: Shuttle Facilities Office, NASA Hqs.

Tonnage Required (Second Stage Only)

	FLTS/YR	TONS/FLT	TONS/DAY	ΔT/DAY
95	200	1600	877	
2000	600	1600	2630	1753
05	1200	1600	5260	2630
10	2000	1600	8767	3457
15	3000	1600	13150	4383
20	3500	1600	15342	2192
25	4000	1600	17534	2192

Cost of Total Capacity (17,534 TONS/DAY)

C = 4.114 B

Assume Single Plant

- Initial Capacity = 877 T/Day ($700M)
- Linear Additions over 20 years to 4.00 B (77 $) @ 165M/YR

APOLLO FACILITY COSTS

	DATE ORIG. COMPLETED	COMPLETION COST	CURRENT RECORD COST
* MOBILE SERVICE STRUCTURE	1967	18.3M	25.1M
* PAD 39A COMPLEX	1965	24.8M	47.4M
* CRAWLER WAY	1966	3.4M	6.8M
* MLP - (ACTUALLY LUT-1 NOV) (STRUCTURAL STEEL ONLY WAS 4M OUTFITTING IS BALANCE)	1967	24.3M	20.2M
** SHUTTLE RUNWAY		27.2M (RY $'s)	
* VAB	1966	177.8	143.1

SOURCES:

* KSC REAL PROPERTY OFFICER

** HQS. FACILITIES OFFICE

1.4.2 <u>Reception</u> (Rectenna)

There are 224 rectenna in the total system, each covering 37.5 square miles of 1.045 X 10^9 sq. ft. The total area required to purchase would probably be larger. All costs (except land and land preparation) were estimated on quantity, weight, complexity etc. bases then reduced to a cost per unit area using these area numbers.

<u>Detailed Assumptions</u>:

1.4.2.1 <u>Land</u>

224 sites, 1.045 X 10 ft^2, 43560 ft^2/acre,
$650/acre
for a total cost of $3,492,943,000

cost/site	$15,593,496
cost/ft^2	$.015
cost/KW	$3.12

Perspective: For an area reasonably close to this size it may be difficult to buy land at $650 per acre, but this is only about .3% of the cost of a rectenna so that it is not a real driver.

1.4.2.2 <u>Site Preparation</u>

Same area as the land, cost $1800 per acre.

Total cost $9,672,768,000

Cost/site	$43,182,000
Cost/ft^2	$.041
Cost/KW	$8.64

Perspective - this highly dependent on the exact location but since it is only about .9% of this cost, it is not a dominating factor.

1.4.2.3 <u>Structure</u>

The drawing in Figure IV. D. (1) b. -1 on page IV. -D-1-b-2 of Vol II of the reference 1 was used as a basis for estimating the cost.

This is a 16 ft. module

Total cost $595,084,544,000

Cost/site	2,656,627,000
Cost/ft^2	$2.54
Cost/KW	$531.32

Perspective - This is the cost driver, 58% of the total rectenna cost.

Bovay (study contractor) estimated the cost of a 96 ft module including ground plane at $15,660 (System 2 all aluminum). This would be equivalent to $2610 per 16 ft module. If the cost of the ground plane (see below) is included in the NASA estimate, the cost is $2500.

1.4.2.4 Dipoles

The drawing on page IV_D-1-5 of Volume II of the reference 1 was used as the basis for estimating the cost of this item. The reference 1 gave a quantity of 15×10^9 dipole per rectenna.

Total cost $273,419,776,000

Cost/site	$1,220,624,000
Cost/ft^2	$1.168
Cost/KW	$244.12

Perspective - This is the second most important driver - 27%

1.4.2.5 Ground Plane

The drawing on page IV-D1-6 was used as the basis for this estimate.

Total Cost $47,413,872,000

Cost/site	$211,669,070
Cost/ft^2	$.203
Cost/KW	42.33

Perspective - This not a cost driver 4.6%

1.4.2.6 Power Collection and Management

The data on page IV-D-2-7 was used as the source for this estimate. Assume option 1 and add 30% for G&A, fee and profit

Total Cost $69,504,354,000

Cost/site	$310,287,729
Cost/ft^2	$.297
Cost/KW	$62.06

Perspective - This is only 6.8% of total cost and well understood compared to some other parts.

1.4.2.9 Integration and Test

This was based on the cost and complexity of the components being integrated into the system.

Total Cost $24,030,860,000

Cost/site	$107,281,070
Cost/ft^2	$.103
Cost/KW	$21.46

Perspective - only 2% of total cost.

Summary of Costs

Total Cost of one Rectennna = $4.56 B

$/KW = $931

The following reports were used as references and in the compilation of this data:

1. Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts. Vol. I & II, JCS-11568, Aug. 31, 1976.

2. NASA MSFC TM X-73344.

3. JPL 900-780.

4. ECON 76-145-2.

5. Analysis and Derivation of Cost Estimating Relationships and Trends for Airframe Structural Elements. NASA CR-132736, Planning Research Corporation, Oct. 15, 1975.

6. CSM Cost/Schedule/Technical Characteristics Study. Rockwell Space Division, SD 71-35, April 30, 1971.

7. C-5 Cost, Schedule, and Technical Characteristics Study. MSC-07018, Lockheed, Ga., Nov. 17, 1972.

8. Avionics Cost/Schedule Study RCA, MSC-05178, Sept. 1, 1972.

9. Space System Cost Model RCA, Contract NAS 9-13562, March 31, 1975.

10. Earth Orbital Space Station Rockwell Phase B Final Report, SD-70-154, July 31, 1970.

11. Munson and Paczynski: Heavy Lift Launch Vehicle Launch and Landing Studies, NASA/JSC/WSTF, 1976-77.

12. Space Station Costs and Schedule Data, McDonnell Douglas, MDC G0646, Aug. 1970.

13. Advanced Spacecraft Systems Cost Analysis Study. McDonnel Douglas, MSC-01248, Jan. 2, 1970.

14. Bovay Engineers, Inc., presentation of results of rectenna design study, untitled, undated.

SECTION X

APPENDIX A

COST COMPUTER PROGRAM SAMPLE OUTPUT

```
****************
TRANSPORTATION INPUT DATA
 BASELINE SOLAR CELL CASE
NYR=   31          IYR= 1996FUELCC=         435.000OMASS=             35.00
FLTMASS=        250.00TLIFE=           30.00FUELPT=           470.00PFLT=          380.00
ROTHYR=           4.00PCTVP=          230.00PTMASS=            35.00HLVPL=         700.00
TURNPCE=          6.00HLIF=           300.00AVAIL=              .800PRAT=            .00
FCOTVF=   1000000.00CHLLVF=   230000000.00COTVF=   1500000.000PLVF=   1000000.00
CCOTV=               .00CHLLV=              .00POTV=               .000PLV=           .00
PLVP=            50.00PLVTR=           11.00VLIFE=           100.00LIFE=          10.00
**************
SATELLITE INPUT DATA
UNITN=     .34000000+06          GRO.F=      .15000000+01
          COMPONENT MASSES                   COST ESTIMATING RATIOS
SCELLM=     .24792664+05         SCELLC=      .44434403+10
 CONCM=     .47305133+04          CONCC=      .86774332+08
STRUCM=     .28511566+04         STRUCC=      .70000000+04
PLISTM=     .28428912+04         POISTC=      .40000000+04
 GENPM=     .92460000+04          GENPC=      .20000000+04
 WAGDM=     .40320000+04          WAGDC=      .70000000+05
ASTRUM=     .12700000+04         ASTRUC=      .70000000+05
ADISTM=     .15700000+03         ADISTC=      .40000000+05
RJOINM=     .33500000+03         RJOINC=      .10000000+06
 PCONM=     .35600000+03          PCONC=      .56000000+02
POINTM=     .10000000+01         POINTC=      .15000000+07
OTHERM=     .53700000+03         OTHERC=      .10000000+07
**********************
GROUND SYSTEM INPUT DATA
A=      10.00       B=       13.00      S=      .10      LAND=      .15      PREP=      .40
POW=     2.50    GMATFR=     10.00     ZONE=      .15
ELEMT=    .19000000+03 CELEMT=    .30000000-01
************
ASSEMBLY SYSTEM-INPUT DATA
      NO. OF  MACHINES          UNIT MASS MT            COST /MT
BUMN=     .56000000+02 UBRM=      14.5000 CBRM=      .200000+07
CRMN=     .20000000+02 UCRM=      14.5000 CCRM=      .200000+07
CELINN=   .40000000+01UCELIN=     14.5000CCELIN=     .200000+07
REFLIN=   .40000000+01UREFLI=     14.5000CREFLI=     .200000+07
OHIN=     .60000000+01 UOHI=      14.5000 COHI=      .200000+07
AMMN=     .80000000+01 UAMM=      14.5000 CAMM=      .200000+07
FAMN=     .12000000+02 UFAM=      14.5000 CFAM=      .200000+07
SUBINN=   .40000000+01USUBIN=     14.5000CSUBIN=     .200000+07
*********
PLEO=    145.00      CLEO=200 [illegible]      GEO=2000000.00      CGGEO=    6000.00
```

X-APP-A-2

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

1

```
***************
FINANCIAL INPUT DATA
PTAXR=          .0000
GLNINF=          .0000
OPPINF=          .0000
   ROR=          .1500
 INFLP=          .0000
    PF=          .9200
  DELR=          .0010
  RATE=          .0010
   OMR=          .0000
 TODTE=     .00000000
  TIME=        10.0000
  INTR=          .0800
```

.38310025+10	.67547690+10	.19364000+11	.12349678+11	.00000000
.00000000	.00000000	.00000000	.00000000	.00000000
.38310025+10	.67547690+10	.20000000+10	.11260678+11	.00000000
.38310025+10	.67547690+10	.20000000+10	.11260678+11	.00000000
.38310025+10	.67547690+10	.20000000+10	.11260678+11	.00000000
.38310025+10	.67547690+10	.20000000+10	.11260678+11	.00000000
.38310025+10	.67547690+10	.20000000+10	.11260678+11	.00000000
.76620051+10	.13509538+11	.21364000+11	.20557356+11	.00000000
.76620051+10	.13509538+11	.40000000+10	.22465356+11	.00000000
.76620051+10	.13509538+11	.40000000+10	.22465356+11	.00000000
.76620051+10	.13509538+11	.40000000+10	.22465356+11	.00000000
.11493007+11	.20264307+11	.23364000+11	.34702034+11	.00000000
.11493007+11	.20264307+11	.60000000+10	.33703035+11	.00000000
.11493007+11	.20264307+11	.60000000+10	.33703035+11	.00000000
.11493007+11	.20264307+11	.60000000+10	.33703035+11	.00000000
.15324013+11	.27019076+11	.25364000+11	.45999713+11	.00000000
.15324013+11	.27019076+11	.80000000+10	.44900713+11	.00000000
.19155013+11	.33773845+11	.27364000+11	.57727391+11	.00000000
.19155013+11	.33773845+11	.10000000+11	.56135391+11	.00000000
.19155013+11	.33773845+11	.10000000+11	.56135391+11	.00000000
.22986015+11	.40528614+11	.29364000+11	.68432069+11	.00000000
.22986015+11	.40528614+11	.12000000+11	.67396069+11	.00000000
.22986015+11	.40528614+11	.12000000+11	.67396069+11	.00000000
.22986015+11	.40528614+11	.12000000+11	.67396069+11	.00000000
.22986015+11	.40528614+11	.12000000+11	.67396069+11	.00000000
.22986015+11	.40528614+11	.12000000+11	.67396069+11	.00000000
.22986015+11	.40528614+11	.12000000+11	.67396069+11	.00000000
.26817018+11	.47283383+11	.31364000+11	.79692747+11	.00000000
.26817018+11	.47283383+11	.14000000+11	.78600747+11	.00000000
.26817018+11	.47283383+11	.14000000+11	.78600747+11	.00000000
.00000000	.00000000	.00000000	.00000000	.00000000

BASELINE SOLAR CELL CASE

YEAR	SPS/YR	SPSCUM
1996	1	1
1997	0	1
1998	1	2
1999	1	3
2000	1	4
2001	1	5
2002	1	6
2003	2	8
2004	2	10
2005	2	12
2006	2	14
2007	3	17
2008	3	20
2009	3	23
2010	3	26
2011	4	30
2012	4	34
2013	5	39
2014	5	44
2015	5	49
2016	6	55
2017	6	61
2018	6	67
2019	6	73
2020	6	79
2021	6	85
2022	6	91
2023	7	98
2024	7	105
2025	7	112
2026	0	112

YEAR	VEHICLE FLIGHTS/YEAR COTV	PCTV	PLV	HLLV	VEHICLES CONSTRUCTED/YEAR COTV	POTV	PLV	HLLV	CUMULATIVE NO. OF VEHICLES COTV	POTV	PLV	HLLV
1996	347	6	34	366	11	1	1	5	11	1	1	9
1997	0	0	0	0	0	0	0	0	11	1	1	9
1998	316	6	34	333	11	0	0	0	22	1	1	9
1999	316	6	34	333	10	0	0	1	32	1	1	10
2000	316	6	34	333	11	0	0	1	43	1	1	11
2001	316	6	34	333	10	0	0	1	53	1	1	12
2002	316	6	34	333	11	0	1	1	64	1	2	13
2003	662	13	68	696	22	0	0	11	86	1	2	24
2004	631	13	68	664	21	1	1	1	107	2	3	25
2005	631	13	68	664	21	0	1	2	128	2	4	27
2006	631	13	68	664	21	1	0	2	149	3	4	29
2007	977	20	102	1029	32	0	1	12	181	3	5	41
2008	947	20	102	996	32	1	1	2	213	4	6	43
2009	947	20	102	996	32	1	1	3	245	5	7	46
2010	947	20	102	996	31	0	1	4	276	5	8	50
2011	1293	27	136	1361	43	1	2	11	319	6	10	61
2012	1262	27	136	1328	42	1	1	5	361	7	11	66
2013	1608	33	170	1693	54	1	2	12	415	8	13	78
2014	1577	33	170	1659	52	1	1	6	467	9	14	84
2015	1577	33	170	1659	53	2	2	5	520	11	16	89
2016	1923	40	204	2024	64	1	2	14	584	12	18	103
2017	1893	40	204	1992	63	1	2	6	647	13	20	109
2018	1893	40	204	1992	63	2	2	6	710	15	22	115
2019	1893	40	204	1992	63	1	2	7	773	16	24	122
2020	1893	40	204	1992	64	1	2	7	837	17	26	129
2021	1893	40	204	1992	63	2	2	6	900	19	28	135
2022	1893	40	204	1992	63	1	2	7	963	20	30	142
2023	2239	47	238	2357	74	2	3	16	1037	22	33	158
2024	2208	47	238	2323	74	1	2	6	1111	23	35	164
2025	2208	47	238	2323	74	2	3	8	1185	25	38	172
2026	0	0	0	0	0	0	0	0	1185	25	38	172

TOTAL FLIGHTS
COTV= 35557
POTV= 742
PLV= 3808
HLLV= 37417

YEAR	PERSONNEL	ROUND TRIPS	TOTAL SPS MASS IN GEO
1995	389.	1556.	76862.
1997	0.	0.	76862.
1998	389.	1556.	153724.
1999	389.	1556.	230586.
2000	389.	1556.	307447.
2001	389.	1556.	384309.
2002	389.	1556.	461171.
2003	778.	3112.	614895.
2004	778.	3112.	768619.
2005	778.	3112.	922342.
2006	778.	3112.	1076066.
2007	1167.	4668.	1306652.
2008	1167.	4668.	1537237.
2009	1167.	4668.	1767823.
2010	1167.	4668.	1998409.
2011	1556.	6224.	2305856.
2012	1556.	6224.	2613304.
2013	1945.	7780.	2997613.
2014	1945.	7780.	3381922.
2015	1945.	7780.	3766232.
2016	2334.	9336.	4227403.
2017	2334.	9336.	4688574.
2018	2334.	9336.	5149745.
2019	2334.	9336.	5610916.
2020	2334.	9336.	6072088.
2021	2334.	9336.	6533259.
2022	2334.	9336.	6994430.
2023	2723.	10892.	7532463.
2024	2723.	10892.	8070496.
2025	2723.	10892.	8608529.
2026	0.	0.	8608529.

MASS TO BE CARRIED BY FLLV-PER-YEAR

YEAR	SPS MASS	O/M MASS	COTV FUEL MASS	POTV FUEL MASS	COTV VEH MASS	POTV VEH MASS	ASSEMBLY MACH.	TOTAL MASS
1996	76862.	0.	164855.	3213.	365.	35.	8682.	255975.
1997	0.	0.	0.	0.	0.	0.	0.	0.
1998	76862.	0.	150100.	3213.	365.	0.	0.	232533.
1999	76862.	0.	150100.	3213.	350.	0.	0.	232458.
2000	76862.	0.	150100.	3213.	365.	0.	0.	232533.
2001	76862.	0.	150100.	3213.	350.	0.	0.	232458.
2002	76862.	0.	150100.	3213.	365.	0.	0.	232533.
2003	153724.	0.	314455.	6427.	770.	0.	8682.	487998.
2004	153724.	0.	299725.	6427.	735.	35.	0.	464591.
2005	153724.	0.	299725.	6427.	735.	0.	0.	464556.
2006	153724.	0.	299725.	6427.	735.	35.	0.	464591.
2007	230586.	0.	464075.	9640.	1120.	0.	8682.	714021.
2008	230586.	0.	449825.	9640.	1120.	35.	0.	657134.
2009	230586.	0.	449825.	9640.	1120.	35.	0.	657124.
2010	230586.	0.	449825.	9640.	1085.	0.	0.	657054.
2011	307447.	0.	614175.	12854.	1505.	35.	8682.	952588.
2012	307447.	0.	599450.	12654.	1470.	35.	0.	929146.
2013	384709.	0.	763800.	16067.	1890.	35.	8682.	1164646.
2014	384709.	0.	749075.	16067.	1820.	35.	0.	1161169.
2015	384709.	0.	749075.	16067.	1855.	70.	0.	1161239.
2016	461171.	0.	913425.	19281.	2240.	35.	8682.	1416669.
2017	461171.	0.	899175.	19281.	2205.	35.	0.	1353702.
2018	461171.	0.	899175.	19281.	2205.	70.	0.	1353737.
2019	461171.	0.	899175.	19281.	2205.	35.	0.	1353702.
2020	461171.	0.	899175.	19281.	2240.	35.	0.	1353737.
2021	461171.	0.	899175.	19281.	2205.	70.	0.	1353737.
2022	461171.	0.	899175.	19281.	2205.	35.	0.	1353702.
2023	538033.	0.	1063525.	22494.	2590.	70.	8682.	1649202.
2024	538033.	0.	1048800.	22494.	2590.	35.	0.	1625710.
2025	538033.	0.	1048800.	22494.	2590.	70.	0.	1625755.
2026	0.	0.	0.	0.	0.	0.	0.	0.

YEAR	FLIGHT COST PER YEAR-MILLIONS OF DOLLARS				VEHICLE COST PER YEAR MILLIONS OF DOLLARS				TOTAL COST
	COTV	PCTV	PLV	HLLV	COTV	POTV	PLV	HLLV	
1996	3470.	101.	340.	8418.	0.	0.	0.	0.	12330.
1997	0.	0.	0.	0.	0.	0.	0.	0.	0.
1998	3160.	101.	340.	7659.	0.	0.	0.	0.	11261.
1999	3160.	101.	340.	7659.	0.	0.	0.	0.	11261.
2000	3160.	101.	340.	7659.	0.	0.	0.	0.	11261.
2001	3160.	101.	340.	7659.	0.	0.	0.	0.	11261.
2002	3160.	101.	340.	7659.	0.	0.	0.	0.	11261.
2003	6620.	203.	680.	16054.	0.	0.	0.	0.	23557.
2004	6310.	203.	680.	15272.	0.	0.	0.	0.	22465.
2005	6310.	203.	680.	15272.	0.	0.	0.	0.	22465.
2006	6310.	203.	680.	15272.	0.	0.	0.	0.	22465.
2007	9770.	304.	1021.	23667.	0.	0.	0.	0.	34762.
2008	9470.	304.	1021.	22508.	0.	0.	0.	0.	33303.
2009	9470.	304.	1021.	22508.	0.	0.	0.	0.	33303.
2010	9470.	304.	1021.	22508.	0.	0.	0.	0.	33303.
2011	12930.	406.	1361.	31303.	0.	0.	0.	0.	46000.
2012	12620.	406.	1361.	30544.	0.	0.	0.	0.	44931.
2013	16080.	507.	1701.	38939.	0.	0.	0.	0.	57227.
2014	15770.	507.	1701.	38157.	0.	0.	0.	0.	56135.
2015	15770.	507.	1701.	38157.	0.	0.	0.	0.	56135.
2016	19230.	609.	2041.	46552.	0.	0.	0.	0.	68432.
2017	18930.	609.	2041.	45816.	0.	0.	0.	0.	67396.
2018	18930.	609.	2041.	45816.	0.	0.	0.	0.	67396.
2019	18930.	609.	2041.	45816.	0.	0.	0.	0.	67396.
2020	18930.	609.	2041.	45816.	0.	0.	0.	0.	67396.
2021	18930.	609.	2041.	45816.	0.	0.	0.	0.	67396.
2022	18930.	609.	2041.	45816.	0.	0.	0.	0.	67396.
2023	22390.	710.	2381.	54211.	0.	0.	0.	0.	79693.
2024	22080.	710.	2381.	53429.	0.	0.	0.	0.	78601.
2025	22080.	710.	2381.	53429.	0.	0.	0.	0.	78601.
2026	0.	0.	0.	0.	0.	0.	0.	0.	0.

SECTION X

APPENDIX B

COST COMPUTER PROGRAM LISTING

```
@FOR,IS COST,COST
FOR-S1E3-04/25/77-15:49:22 (,0)

   MAIN PROGRAM

   STORAGE USED: CODE(1) 002141; DATA(0) 010262; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

     0003   FINANC
     0004   NINTR$
     0005   NRDU$
     0006   NIO1$
     0007   NIO2$
     0010   NRNL$
     0011   NWDU$
     0012   NIO1$
     0013   NSTOP$

   STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

     0001   000004 1L        0001   001740 1022G     0001   001765 1040G     0001   001514 106L      0001   001543 107
     0001   002035 1076G     0001   001214 108L      0001   001561 109L      0001   001042 110L      0001   001010 111
     0001   001075 112L      0001   002026 1122G     0001   001577 113L      0001   002116 1141G     0001   001007 151
     0000   007411 2001F     0000   007421 2002F     0000   007423 2003F     0000   007424 2004F     0000   007425 200
     0000   007442 2006F     0000   007446 2007F     0000   007512 2008F     0000   007661 2888F     0000   010026 289
     0000   010075 2891F     0000   010067 2898F     0001   001625 3001L     0001   001670 3002L     0001   001634 300
     0001   001116 3004L     0001   001121 3005L     0001   001125 3006L     0001   001232 4001L     0001   001277 400
     0001   001302 4003L     0001   001306 4004L     0001   000644 432G      0001   000704 462G      0001   001355 500
     0001   001422 5002L     0001   001425 5003L     0001   001431 5004L     0001   001546 666L      0001   000714 667
     0001   001217 663L      0001   001342 669L      0000   007516 7000F     0000   007570 7001F     0000   007610 700
     0000   007655 7003F     0001   001161 7777L     0000   007162 7778F     0000   007263 8111F     0000   007534 999
     0000 R 006251 A         0000 R 006232 ADISTC    0000 R 006216 ADISTM    0000 R 006270 AMMN      0000 R 006322 AFE
     0000 R 007223 ASSEM     0000 R 005641 ASSY      0000 R 006231 ASTRUC    0000 R 006215 ASTRUM    0000 R 006411 ASU
     0000 R 005167 AVAIL     0000 R 006330 A1        0000 R 006131 A2        0000 R 006252 B         0000 R 006263 BBM
     0000 R 006327 BUFFER    0000 R 006313 CAMM      0000 R 006124 CAREA     0000 R 006306 CCBM      0000 R 006310 CCE
     0000 R 005246 CCONC     0000 R 006175 CCOTV     0000 R 006171 CCOTVF    0000 R 006307 CCRM      0000 R 006312 CCM
     0000 R 005245 CELC      0000 R 006261 CELEMT    0000 R 006465 CELINN    0000 R 006314 CFAM      0000 R 006317 CCE
     0000 R 005176 CHLLV     0000 R 006172 CHLLVF    0000 R 006316 CLEO      0000 R 005204 CLIFE     0000 R 000017 CMM
     0000 R 006154 COMASS    0000 R 006224 CONCC     0000 R 006215 CONCM     0000 R 006332 CONV      0000 R 006213 COS
     0000 R 006341 COSTX     0000 R 002752 COTV      0000 R 002525 COTVFL    0000 R 002607 COTVFU    0000 R 002671 COT
     0000 R 006240 CPLV      0000 R 006174 CPLVF     0000 R 006177 CPOTV     0000 R 006173 CPOTVF    0000 R 006320 CCG
     0000 R 006247 CRATIO    0000 R 006311 CREFLI    0000 R 006464 CPMN      0000 R 006273 CRCIG     0000 R 006274 CRC
     0000 R 006315 CSUBIN    0000 R 003035 CTF       0000 R 006405 CUM       0000 R 007201 CVCONS    0000 R 006353 C1
     0000 R 006364 C10       0000 R 006354 C2        0000 R 006355 C3        0000 R 006356 C4        0000 R 006357 C5
     0000 R 006365 C6        0000 R 006361 C7        0000 R 006362 C8        0000 R 006363 C9        0000 R 006466 CCU
     0000 R 005412 DD        0000 R 006267 DMIN      0000 R 006400 DPCUM     0000 R 006377 DTD       0000 R 005377 CLM
     0000 R 006342 ELC       0000 R 006266 ELEMT     0000 R 006456 FACTO     0000 R 006271 FAMN      0000 R 006410 FCU
     0000 R 006244 FFF       0000 R 006155 FLTMAS    0000 R 006413 FPVCH     0000 R 006153 FUELCO    0000 R 006157 FLEL
     0000 R 006227 GENRC     0000 R 006211 GENRK     0000 R 006256 GMATER    0000 R 005475 GRDCOS    0000   006763 GROL
     0000 R 006106 GROWF     0000 R 004475 HCONST    0000 R 004413 HLF       0000 R 006166 HLIF      0000 R 004247 HLL
     0000 R 004103 HLLVF     0000 R 004021 HLLVK     0000 R 006164 HLVPL     0000 I 006313 I         0000 I 006372 ICO
     0000 I 001147 ICOT      0000 I 000411 ICVCON    0000 I 006421 IFLG      0000 I 000637 IHLCON    0000 I 006367 IHLF
     0000 I 006374 III       0000 I 006375 IJK       0000   006416 INPUT     0000 I 001065 IOTVFL    0000 I 005555 IPLC
     0000 I 006370 IPLFLT    0000 I 000327 IPLVFL    0000 I 006371 IPOFLT    0000 I 002245 IPOTVF    0000 I 004413 IPVC
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0000 I 001271 ISPSCU   0000 I 001001 ISPSYR   0000 I 006407 ISUM     0000 I 000721 IYEAR    0000 I 004112 IYR
0000 I 006414 J        0000 I 006415 JK       0000 R 000016 LAND     0000 I 001457 NCOTV    0000 I 001375 NHLLV
0000 I 001313 NHLLVF   0000 R 000000 NOA      0000 I 001023 NPLV     0000 I 001541 NPOTV    0000 R 000001 NRF
0000 R 000015 NTEMP    0000 R 000002 NWG      0000 I 006131 NYR      0000 R 000003 N1       0000 R 000014 N10
0000 R 000004 N2       0000 R 000005 N3       0000 R 000006 N4       0000 R 000007 N5       0000 R 000010 N6
0000 R 000011 N7       0000 R 000012 N8       0000 R 000013 N9       0000 R 002215 OM       0000 R 006170 OPRAT
0000 R 006236 OTHERC   0000 R 006222 OTHERM   0000 R 006234 PCONC    0000 R 006220 PCONM    0000 R 006226 PDISTC
0000 R 006212 PDISTM   0000 R 006160 PFLT     0000 R 002361 PGEO     0000 R 006327 PI       0000 R 005067 PLCONS
0000 R 006202 PLEC     0000 R 004727 PLV      0000 R 005505 PLVFL    0000 R 005151 PLVN     0000 R 006201 PLVP
0000 R 006202 PLVTR    0000 R 006005 PMAGEO   0000 R 003737 POCONS   0000 R 006235 POINTC   0000 R 006221 POINTM
0000 R 003541 POTV     0000 R 003261 POTVFL   0000 R 003345 POTVFU   0000 R 006152 POTVP    0000 R 003427 POTVWT
0000 R 006255 POW      0000 R 006205 POWG     0000 R 006335 POWMGT   0000 R 006254 PREP     0000 R 006275 PRCTS
0000 R 005103 PTMASS   0000 R 003573 PTV      0000 R 006333 REALS    0000 R 006256 REFLIN   0000 R 006213 RJOINC
0000 R 006217 RJOINM   0000 R 006404 RNO      0000 R 006361 ROTYR    0000 R 002443 RTGEO    0000 R 006253 S
0000 R 005557 SAT      0000   006552 SATEL    0000 R 006323 SCAREA   0000 R 006223 SCELLC   0000 R 006207 SCELLM
0000 R 006321 SCONST   0000 R 006326 SCOSTC   0000 R 006334 SITEP    0000 R 006325 SPS      0000 R 001767 SPSCUM
0000 R 006201 SPSGEO   0000 R 002133 SPSMAS   0000 R 005067 SPSS     0000 R 001775 SPSYR    0000 R 006376 SSS
0000 R 006225 STRUCC   0000 R 006211 STRUCM   0000 R 006372 SUBINN   0000 R 006403 SUM      0000 R 006402 SUMP
0000 R 006336 SUPSTR   0000 R 006365 TCOST    0000 R 004331 THLLV    0000 R 004165 THLLVF   0000 R 005401 TITLE
0000 R 006156 TLIFE    0000 R 002277 TOT      0000 R 003163 TOTT     0000 R 005773 TRANS    0000 R 006165 TLRNRD
0000 R 006303 UAMP     0000 R 006276 UBOM     0000 R 006300 UCELIN   0000 R 006241 UCONCM   0000 R 006277 UCRP
0000 R 006302 UDHI     0000 R 006304 UFAM     0000 R 006237 UNITN    0000 R 006242 UPDISM   0000 R 006301 UREFLI
0000 R 006241 USCELM   0000 R 006243 USTRUM   0000 R 006305 USUBIN   0000 R 003117 VCCOTV   0000 R 004557 VCHLLV
0000 R 004641 VCPLV    0000 R 003655 VCPOTV   0000 R 006403 VLIFE    0000 R 006270 WAGDC    0000 R 006214 WAGDM
0000 R 005315 WT       0000 R 006366 WTMACH   0000 R 006352 WTMT     0000 R 006342 WTM1     0000 R 006343 WTM2
0000 R 006344 WTM3     0000 R 006345 WTM4     0000 R 006346 WTM5     0000 R 006347 WTM6     0000 R 006350 WTM7
0000 R 006351 WTM8     0000 R 003101 WTT      0000 R 006257 ZONE
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00101     1*        REAL NOA,NRF,NWG,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,NTEMP                       000000
00103     2*        REAL LAND                                                                 000001
00104     3*        DIMENSION CMMM(50),WTT(50),TOTT(50)                                       000001
00105     4*        DIMENSION IPOTVF(50),IPLVFL(50),ICVCON(50),IPVCON(50),IFLCON(50),         000001
00105     5*       1IHLCON(50),IYEAR(50),ISPSYR(50),IOTVFL(50),ICOT(50),ISPSCU(50),           000001
00105     6*       2NHLLVF(50),NHLLV(50),NCOTV(50),NPOTV(50),NPLV(50),SPSYR(50),              000001
00105     7*       3SPSCUM(50),SPSGEO(50),SPSMAS(50),OM(50),TOT(50),PGEO(50),RTGEO(50)        000001
00105     8*       4,COTVFL(50),COTVFU(50),COTVPA(50),COTV(50),CTF(50),VCCOTV(50),            000001
00105     9*       5CVCONS(50),POTVFL(50),POTVFU(50),POTVWI(50),POTV(50),PTV(50),             000001
00105    10*       6VCPOTV(50),POCONS(50),HLLVM(50),HLLVF(50),THLLVF(50),HLLV(50),            000001
00105    11*       7THLLV(50),HLF(50),HCONST(50),VCHLLV(50),VCPLV(50),PLV(50),                000001
00105    12*       8PLVFL(50),FLCONS(50),PLVA(50),COST(50),WT(50),DUM(50),TITLE(12)           000001
00106    13*        DIMENSION CRDCOS(50),SAT(50),ASSY(50),TRANS(50)                          000001
00107    14*        DIMENSION FMAGEO(50)                                                      000001
00110    15*        DIMENSION SPSS(50)                                                        000001
00111    16*        NAMELIST/INPUT/NYR,IYR,SPSYR,FUELCO,COMASS,FLTMAS,    TLIFE,              000001
00111    17*       1FUELPT,PFLT,RCTYR,POTVF,PTMASS,HLVPL,TLRNRD,HLIF,AVAIL,                   000001
00111    18*       2CPRAT,CCOTVF,CHLLVF,CPOTVF,CPLVF,CCOTV,CHLLV,CPOTV,CPLV,PLVP,             000001
00111    19*       3PLVTR,VLIFE,CLIFE,POWG                                                    000001
00112    20*        NAMELIST/SATEL/GROWF,SCELLM,CONCM,STRUCM,PDISTM,GENRM,WAGDM,              000001
00112    21*       1ASTRUM,ADISTM,RJOINM,PCONM,POINTM,OTHERM,SCELLC,CONCC,STRUCC,             000001
00112    22*       2PDISTC,GENRC,WAGDC,ASTRUC,ADISTC,RJOINC,PCONC,POINTC,OTHERC,UNITN         000001
00112    23*       3,USCELM,UCONCM,UPDISM,USTRUM,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,FFF,         000001
00112    24*       4CELC,CCONC,CRATIC,FACTC                                                   000001
00113    25*        NAMELIST/GROUND/A,B,S,LAND,PREP,POW,GMATER,ZONE,ELEMT,CELEMT              000001
00114    26*        NAMELIST/ASSEM/PLEO,BOMN,CRPN,CELINN,REFLIN,DHIN,AMMN,FAMN,SUBINN,        000001
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00114              1CROTG,CROTL,PRCTS,URBM,UCRM,UCELIN,UREFLI,UDHI,UAMM,UFAP,USUBIN,          000001
00114              2CRBM,CCRM,CCELIN,CREFLI,CDHI,CAMM,CFAM,CSUBIN                            000001
00114              2,CLEO,CGEO,COGEO                                                          000001
00115               SCONST=1.353                                                              000001
00115    1          CONTINUE                                                                  000004
00117               READ(5,2003) TITLE                                                        000009
00122               REA (5,INPUT)                                                             000013
00125               READ(5,GROUND)                                                            000017
00130               READ(5,SATEL)                                                             000023
00133               READ(5,ASSEM)                                                             000027
00135               WRITE(6,2004)                                                             000033
00135     C **** SPS COSTS *****************                                                  000033
00135     C  ***CONVERSION EFFICIENCIES****                                                   000033
00136     C         N1--PHOTOVOLTAIC CONVERSION                                               000033
00136     C         N2--POWER DISTRIBUTION                                                    000033
00136     C         N3--ANTENNA POWER DISTRIBUTION                                            000033
00136     C         N4--DC-RF CONVERSION                                                      000033
00136     C         N5--WAVEGUIDE                                                             000033
00136     C         N6--ALIGNMENT                                                             000033
00136     C         N7--ATMOSPHERIC                                                           000033
00136     C         N8--COLLECTION                                                            000033
00136     C         N9--RF-DC                                                                 000033
00136     C         N10--INTERFACE                                                            000033
00136     C         NOA--OVERALL EFFICIENCY                                                   000033
00140               IF(FFF.NE.0.0) GO TO 7777                                                 000040
00142               NTEMP=N5*N6*N7*N8*N9*N10                                                  000042
00143               NOA=N1*N2*N3*N4*NTEMP                                                     000051
00144               NRF=N4*NTEMP                                                              000057
00145               NWG=NTEMP                                                                 000062
00145     C         SCONST  SOLAR CONSTANT  KW/M2                                             000062
00145     C          SCAREA  SOLAR CELL AREA                                                  000062
00145     C          CAREA CONCENTRATOR AREA                                                  000062
00145     C          AREA  TOTAL AREA                                                         000062
00146               AREA=POWG     /(SCONST*NOA)                                               000064
00147               SCAREA=AREA/CRATIO                                                        000070
00150               CAREA=(AREA-SCAREA)*FACTO                                                 000072
00151               SCELLM=USCELM*SCAREA/1000.                                                000075
00152               CONCM=UCONCM*CAREA/1000.                                                  000101
00153               SCELLC=CELC*SCAREA                                                        000104
00154               CONCC=CCONC*CAREA                                                         000107
00155               STRUCM=USTRUM*AREA/1000.                                                  000112
00156               PDISTM=UPDISM*AREA/1000.                                                  000116
00157               GENRM=17776.*NRF                                                          000122
00160               WAGOM=5423.*NWG                                                           000124
00161     7778 FORMAT(' N1=',F10.6,5X,'N2=',F10.6,5X,'N3=',F10.6,5X,'N4=',F10.6,5X,           000126
00161              1'N5=',F10.6/' N6=',F10.6,5X,'N7=',F10.6,5X,'N8=',F10.6,5X,'N9=',F10.6,    000126
00161              25X,'N10=',F10.6/' NOA=',F10.6,5X,'NRF=',F10.6,5X,'NWG=',F10.6/' AREA='    000126
00161              3E15.6/' USCELM=',E15.6,5X,'UCONCM=',E15.3,5X,'USTRUM=',E15.8,5X,          000126
00161              4'UPDISM=',E15.8/' SCAREA=',E15.8,' CAREA=',E15.6/' CELC=',F10.4,          000126
00161              5' CCONC=',F10.4,' CRATIO=',F10.4)                                         000126
00162               WRITE(6,7778) N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,NOA,NRF,NWG,AREA,            000126
00162              1USCELM,UCONCM,USTRUM,UPDISM,SCAREA,CAREA,CELC,CCONC,CRATIO                000126
00213     7777 CONTINUE                                                                       000163
00214               SPS=GROWF*(SCELLM+CONCM+STRUCM+PDISTM+GENRM+WAGOM+ASTRUM+ADISTM+          000163
00214              1RJOINM+PCONM+POINTM+OTHERM)                                               000163
00215               SCOSTC=SCELLC+CONCC+UNITN*(GENRC+PCONC)+GROWF      *(STRUCM*STRUCC        000200
00215              1+PDISTM*PDISTC+WAGOM*WAGOC+ASTRUM*ASTRUC+ADISTM*ADISTC+RJOINM*            000200
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     2RJOINC,POINTM,POINTC,OTHERM,OTHERC)
C **** GROUND SYSTEM COSTS ***************
C      REALS REAL ESTATE COST
C      SITEP SITE PREPARATION COST
C      POWMGT POWER MANAGEMENT COST
C      SUPSTR SUPPORT STRUCTURE COST
C      BUFFER BUFFER ZONE COST
C      A AND B ARE AXES OF RECTENNA(KM)
C      S IS WIDTH OF BUFFER STRIP(KM)
       PI=3.14159265
       A1=PI/4.*(A+2.*S)*(B+2.*S)
       A2=PI/4.*A*B
       CONV=2000000.
       REALS=LAND*CONV*A1
       SITEP=PREP*CONV*A2
       POWMGT=POW*CONV*A2
       SUPSTR=GMATER*CONV*A2
       BUFFER=ZONE*CONV*(A1-A2)
       ELC=A2*ELEMT*CELEMT*CONV
       COSTX=REALS+SITEP+POWMGT+SUPSTR+BUFFER+ELC
       WRITE(6,8111) TITLE,NYR,IYR,FUELCO,COMASS,FLTMAS,TLIFE,FUELPT,
      1PFLT,RCTYR, PCTVP,PTMASS,HLVPL,TURNRL,FLIF,AVAIL,OMRAT,CCOTVF,
      2CHLLVF,CPCTVF,CPLVF,CCOTV,CHLLV,CPOTV,CPLV,PLVP,PLVTR,VLIFE,CLIFE
       WRITE(6,2868)UNITN,GROWF,SCELLM,SCELLC,CONCM,CONCC,STRUCM,STRUCC,
      1PDISTM,PDISTC,GENRM,GENRC,WAGCM,WAGDC,ASTRUM,ASTRUC,ADISTM,ADISTC,
      2RJOINM,RJOINC,PCONM,PCONC,PCINTM,POINTC,OTHERM,OTHERC
       WRITE(6,2850) A,B,S,LAND,PREP,POW,GMATER,ZONE
       WRITE(6,2858) ELEMT,CELEMT
       WRITE(6,2851)BBMN,UBBM,CBBM,CRMN,UCRM,CCRM,CELINN,UCELIN,CCELIN,
      1REFLIN,UREFLI,CREFLI,DHIN,UDHI,CDHI,AMMN,UAMM,CAMM,FAMN,UFAM,CFAM,
      2SUBINN,USUBIN,CSUBIN,PLEO,CLEO,CGEO,CUCEO
C **** ASSEMBLY SYSTEM COSTS ***************
       WTM1=BBMN*UBBM
       WTM2=CRMN*UCRM
       WTM3=CELINN*UCELIN
       WTM4=REFLIN*UREFLI
       WTM5=DHIN*UDHI
       WTM6=AMMN*UAMM
       WTM7=FAMN*UFAM
       WTM8=SUBINN*USUBIN
       WTMT=WTM1+WTM2+WTM3+WTM4+WTM5+WTM6+WTM7+WTM8
       C1=WTM1*CBBM
       C2=WTM2*CCRM
       C3=WTM3*CCELIN
       C4=WTM4*CREFLI
       C5=WTM5*CDHI
       C6=WTM6*CAMM
       C7=WTM7*CFAM
       C8=WTM8*CSUBIN
       C9=CCGEO*CCEO
       C10=CRGTL*CLEO
       TCOST=C1+C2+C3+C4+C5+C6+C7+C8+C9+C10
C ***  TRANSPORTATION COSTS***********
       WTMACH=CQGEO+WTMT+CRGTL
       IHLFLT=0
       IPLFLT=0
       IPOFLT=0
```

```
      ICOFLT=0
      DO 989 I=1,NYR
      NCOTV(I)=0
      NPOTV(I)=0
      NPLV(I)=0
  989 CONTINUE
      III=0
      IJK=0
      SSS=0.0
      DTD=VLIFE
      DPCUM=TLIFE
      IFLG=0
      SUMM=0.0
      SUM=0.
      RNO=0.
      CUM=0.0
      CCUM=HLIF
      ISUM=0
      FCUM=0.
      ASUM=0.0
      CC=CLIFE
      FPVEH=365.*AVAIL/TURNRD
C     ****************************************************************
C     ****************************************************************
C  ********TRANSPORTATION INPUT*****************
C     NYR,NUMBER OF YEARS IN SCENARIO
C       IYR,FIRST YEAR IN SCENARIO
C       SPSYR,NUMBER OF SPS TO BE PUT UP IN YEAR I
C       FUELCO,COTV FUEL MASS/FLIGHT
C       COMASS,COTV VEHICLE MASS/FLIGHT
C       FLTMAS,COTV MASS PER FLIGHT
C       TLIFE,POTV LIFETIME
C       FUELPT,FUEL PER POTV FLIGHT
C       PFLT,NUMBER OF PERSONNEL IN GEO PER SPS
C       ROTYR,ROTATIONS PER YEAR
C       POTVF,NUMBER OF PERSONNEL PER POTV FLIGHT
C       PTMASS,POTV MASS
C       HLVPL,HLLV PAYLOAD
C       TURNRD,TURNAROUND TIME FOR HLLV
C       HLIF,HLLV LIFETIME
C     AVAIL , HLLV AVAILABILITY
C       OMRAT, FRACTION OF SPS COST THAT IS O AND M
C       CCOTVF,COST PER COTV FLIGHT
C       CHLLVF,COST PER HLLV FLIGHT
C       CPOTVF,COST PER POTV FLIGHT
C       CPLVF ,COST PER PLV  FLIGHT
C       CCOTV,COTV VEHICLE COST PER VEHICLE
C       CHLLV,HLLV VEHICLE COST PER VEHICLE
C       CPOTV,POTV VEHICLE COST PER VEHICLE
C       CPLV ,PLV  VEHICLE COST PER VEHICLE
C       PLVP PERSONNEL PER PLV FLIGHT
C       PLVTR,PLV TURNAROUND TIME
C       VLIFE,PLV LIFETIME
C       CLIFE,COTV LIFETIME
C            **********************************************8
C  ***********ASSEMBLY SYSTEM INPUTS******************
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C      PLEO,NUMBER OF PERSONNEL IN LEO PER SPS
C      BBMN,NO. OF BEAM BUILDING MACHINES
C      CRMN,NO. OF CABLE RIGGING MACHINES
C      CELINN,NO. OF CELL INSTALLERS
C      REFLIN,NO.  OF REFLECTOR INSTALLERS
C      DHIN, NO. OF DISTRIBUTION HARNESS INSTALLERS
C      AMMN, NO. OF MANNED MANIPULATORS
C      FAMN, NO. OF FACILITY MANIPULATORS
C      SUBINN, NO. OF SUBARRAY INSTALLERS
C      CRQTG, CREW QUARTERS MASS IN GEO/SPS
C      CRQTL,CREW QUARTERS MASS IN LEO
C      PRGTS,PERSONNEL REQUIREMENTS IN GEO MT/PERSON/YR
C      COGEO,CREW QUARTERS IN GEO PER ASSEMBLY MACHINE
C      ** --UNIT MASSES**
C      UBBM,UCRM,UCELIN,UREFLI,UDHI,UAMM,UFAM,USUBIN
C     *** COST PER METRIC TON ***
C      CBBM,CCRM,CCELIN,CREFLI,CDHI,CAMM,CFAM,CSUBIN
C      CLEO,CGEO CREW QUARTERS COST/MT IN LEO AND GEO
C             *****************************************************
C              *************************************MMMMMMMMMMMM*********
C ***********GROUND SYSTEM INPUT*******************
C      A,B,-AXES OF RECEIVING ANTENNA ELLIPSE,KM
C      S, WIDTH OF BUFFER STRIP,KM
C      LAND,LAND COST $/M2
C      PREP, SITE PREPARATION COST $/M2
C      POW,POWER MANAGEMENT COST $/M2
C      GMATER,SUPPORT STRUCTURE COST $/M2
C      ZONE,BUFFER ZONE COST $/M2
C      ELEMT--NO.  OF ELEMENTS PER M2 FOR RECTENNA
C      CELLMT--COST PER RECTENNA ELEMENT
C         *************************************************************8
C  ***********************************************************************
C  *******SATELLITE INPUT **************
C      CELC---SOLAR CELL COST PER UNIT AREA $/M2
C      CRATIC  CONCENTRATION RATIO
C      CONCC  CONCENTRATOR COST PER UNIT AREA $/M2
C      GF,MASS GROWTH FACTOR
C      SCELLM,SOLAR CELL MASS MT
C      CONCM,CONCENTRATOR MASS MT
C      STRUCM,STRUCTURE MASS MT
C      PDISTM,POWER DISTRIBUTION MASS,MT
C      GENRM,MICROWAVE GENERATOR MASS MT
C      WAGDM,WAVEGUIDE MASS MT
C      ASTRUM,ANTENNA STRUCTURE MASS MT
C      ADISTM,ANTENNA DISTRIBUTION MASS,MT
C      RJOINM,ROTARY JOINT MASS MT
C      PCONM,PHASE CONTROL MASS MT
C      POINTM,POINTING MASS MT
C      OTHERM,OTHER MASS MT
C  *********COST ESTIMATING RATIOS *************
C **  SCELLC $,CONCC $,
C  **  SCELLC $, CONCC $,STRUCC $/MT,PDISTC $/MT,GENRC $/UNIT,WAGDC $/MT
C  **ASTRUC $/MT,ADISTC $/MT,RJOINC $/MT,PCONC $/UNIT,POINTC $/MT,OTHERC $/MT
C      UNITN,NO. OF MICROWAVE GENERATOR AND PHASE CONTROL UNITS
C      *************************************************************8******
C  ************************************************************************
C      PMAGEO, PERSONNEL MASS REQUIRED/PERSON/YEAR IN GEO
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      C        IYEAR,LIST OF YEARS IN SCENARIO
      C        SPS,MASS OF ONE SPS
      C        SPSCUM,CUMULATIVE SPS IN YEAR I
      C        SPSGEO,SPS MASS IN GEO CUMULATIVE
      C        OM,O AND M MASS PER YEAR
      C        SPSMAS,SPS MASS PER YEAR
      C        TOT,TOTAL MASS/YEAR OM+SPSMAS
      C      COTVFL,COTV FLIGHTS/YEAR
      C        COTVFU,COTV  FUEL MASS/YR
      C        COTVMA,COTV VEHICLE MASS/YR
      C        PGEO,PERSONNEL IN GEO
      C        RTGEO,ROUNDTRIPS TO GEO
      C        POTVFL,NUMBER OF POTV FLIGHTS
      C        POTVFU,POTV FUEL MASS
      C        NPOTV,NUMBER OF POTVS
      C        POTVWT,WEIGHT OF POTVS
      C        HLLVM,MASS TO BE LIFTED BY HLLV TO LEO
      C        NHLLVF,NUMBER OF HLLV FLIGHTS PER YEAR
      C        NHLLV,NUMBER OF HLLVS
      C        WTMACH,WEIGHT OF ASSEMBLY MACHINE AND CREW QUARTERS TO GEO
      C        JK, NO. OF NEW ASSEMBLY MACHINES
      C        CTF IS COTV FLIGHT COST PER YEAR
      C        HLF IS HLLV FLIGHT COST PER YEAR
      C        PTV IS POTV FLIGHT COST PER YEAR
      C        PLV IS PLV  FLIGHT COST PER YEAR
      C        VCCOTV IS COTV VEHICLE COST PER YEAR
      C        VCHLLV IS HLLV VEHICLE COST PER YEAR
      C        VCPOTV IS POTV VEHICLE COST PER YEAR
      C        VCPLV  IS PLV  VEHICLE COST PER YEAR
      C        HCONST(I),NO. OF HLLV CONSTRUCTED IN YEAR I
      C        CVCONS(I),NO. OF COTV CONSTRUCTED IN YEAR I
      C        POCONS(I),NO. OF POTV CONSTRUCTED IN YEAR I
      C        PLCONS(I),NO. OF PLV  CONSTRUCTED IN YEAR I
               DO 1001 I=1,NYR
               J=I-1
               IYEAR(I)=IYR+I-1
               CUM=CUM+SPSYR(I)
               SPSCUM(I)=CUM
         1001  CONTINUE
               SAT(I)=SCOSTC*SPSYR(I)
               GROCOS(I)=COSTX*SPSYR(I)
               SPSGEO(I)=SPS*SPSCUM(I)
               OM(I)=SPSGEO(I)*OMRAT
               SPSMAS(I)=SPSYR(I)*SPS
               ISPSYR(I)=SPSYR(I)
               ISPSCU(I)=SPSCUM(I)
      C        *****POTV CALCULATIONS***********
               CMMM(I)=CRCTC*SPSYR(I)
               ASSY(I)=CMMM(I)*CCEO
               PGEO(I)=PFLT*SPSYR(I)
               RTGEO(I)=PGEO(I)*ROTYR
               POTVFL(I)=RTGEO(I)/POTVP
               POTVFU(I)=FUELPT*POTVFL(I)
               SUMM=POTVFL(I)+SUMM
          667  CONTINUE
               IF(DPCUM.GE.SUMM) GO TO 151
               DPCUM=DPCUM+TLIFE
```

I

```
      IFLG=IFLG+1
      GO TO 667
151   CONTINUE
      IF(SUMM.GT.0.0.AND.SUMM.LT.TLIFE) NPOTV(I)=1
      NPOTV(I)=NPOTV(I)+IFLG
      POTV(I)=NPOTV(I)
      IF(I.NE.1) GO TO 110
      JK=ISPSYR(I)
      GO TO 111
110   CONTINUE
      JK=ISPSYR(I)-ISPSYR(J)
      IF(JK.LE.0) GO TO 112
111   CONTINUE
      IF(SUM.GE.SPSYR(I)) GO TO 112
      RNO=JK
      SUM=SUM+RNO
      WT(I)=WTMACH*RNO
      WTT(I)=(WTMACH-CROTL)*RNO
      ASSY(I)=ASSY(I)+TCOST*RNO
      GO TO 113
112   CONTINUE
      WT(I)=0.
      WTT(I)=0.
113   CONTINUE
      IF(I.EQ.1) GO TO 3004
      IF(NPOTV(I).GE.NPOTV(J)) GO TO 3005
      NPOTV(I)=NPOTV(J)
      POTV(I)=NPOTV(I)
      POCONS(I)=0.0
      GO TO 3006
3004  CONTINUE
      POCONS(I)=POTV(I)
      GO TO 3006
3005  CONTINUE
      POCONS(I)=POTV(I)-POTV(J)
3006  CONTINUE
      IPVCON(I)=POCONS(I)
      IPOTVF(I)=POTVFL(I)
      VCPOTV(I)=POCONS(I)*CPOTV/1000000.
      PMAGEO(I)=PROTS*FGEO(I)
      TOT(I)=CM(I)+SPSMAS(I)+WTT(I)+PMAGEO(I)+CMMM(I)
      TOTT(I)=CM(I)+SPSMAS(I)+WT(I)+PMAGEO(I)+CMMM(I)
      DUM(I)=TOT(I)/FLTMAS
      IOTVFL(I)=TOT(I)/FLTMAS
C *********COTV CALCULATIONS ***************************
      COTVFL(I)=IOTVFL(I)
      IF(DUM(I).EQ.COTVFL(I)) GO TO 108
      IOTVFL(I)=IOTVFL(I)+1
      COTVFL(I)=IOTVFL(I)
108   CONTINUE
      ASUM=COTVFL(I)+ASUM
668   CONTINUE
      IF(DD.GE.ASUM) GO TO 4001
      DD=DD+CLIFE
      III=III+1
      GO TO 668
4001  CONTINUE
```

```
      IF(ASUM.GT.0.0.AND.ASUM.LT.CLIFE) NCOTV(I)=1
      NCOTV(I)=NCOTV(I)+III
      COTV(I)=NCOTV(I)
      IF(I.EQ.1) GO TO 4002
      IF(NCOTV(I).GE.NPOTV(J)) GO TO 4003
      NCOTV(I)=NCOTV(J)
      COTV(I)=NCOTV(I)
      CVCONS(I)=0.
      GO TO 4004
 4002 CONTINUE
      CVCONS(I)=COTV(I)
      GO TO 4004
 4003 CONTINUE
      CVCONS(I)=COTV(I)-COTV(J)
 4004 CONTINUE
      ICVCON(I)=CVCONS(I)
      VCCOTV(I)=CVCONS(I)*CCOTV/1000000.
      COTVFL(I)=COTVFL(I)*FUELCO
      ICOT(I)=COTVFL(I)
C *********PLV  CALCULATIONS *************************
      PLVFL(I)=(FTGEO(I)+PLEO*SPSYR(I))/PLVP
      SSS=PLVFL(I)+SSS
  669 CONTINUE
      IF(DTD.GE.SSS) GO TO 5001
      DTD=DTD+VLIFE
      IJK=IJK+1
      GO TO 669
 5001 CONTINUE
      IF(SSS.GT.0.0.AND.SSS.LT.VLIFE) NPLV(I)=1
      NPLV(I)=NPLV(I)+IJK
      PLVN(I)=NPLV(I)
      IF(I.EQ.1) GO TO 5002
      IF(NPLV(I).GE.NPLV(J)) GO TO 5003
      NPLV(I)=NPLV(J)
      PLVN(I)=NPLV(I)
      PLCONS(I)=0.0
      GO TO 5004
 5002 CONTINUE
      PLCONS(I)=PLVN(I)
      GO TO 5004
 5003 CONTINUE
      PLCONS(I)=PLVN(I)-PLVN(J)
 5004 CONTINUE
      IPLCON(I)=PLCONS(I)
      IPLVFL(I)=PLVFL(I)
      VCPLV(I)=PLCONS(I)*CPLV/1000000.
C *********HLLV CALCULATIONS *************************
      COTVMA(I)=COMASS*CVCONS(I)
      PCTVWT(I)=FTMASS*POCONS(I)
      HLLVM(I)=TCTT(I)+COTVFL(I)+COTVMA(I)+PCTVWT(I)+POTVFU(I)
      NHLLVF(I)=HLLVM(I)/HLVPL
      HLLVF(I)=NHLLVF(I)
      THLLVF(I)=HLLVM(I)/HLVPL
      IF(THLLVF(I).EQ.HLLVF(I)) GO TO 106
      NHLLVF(I)=NHLLVF(I)+1
      HLLVF(I)=NHLLVF(I)
  106 CONTINUE
```

```
      NHLLV(I)=HLLVF(I)/FPVEH
      HLLV(I)=NHLLV(I)
      THLLV(I)=HLLVF(I)/FPVEH
      IF(THLLV(I).EQ.HLLV(I)) GO TO 107
      NHLLV(I)=NHLLV(I)+1
      HLLV(I)=NHLLV(I)
  107 CONTINUE
      FCUM=HLLVF(I)+FCUM
  666 CONTINUE
      IF(DCUM.GE.FCUM) GO TO 109
      DCUM=DCUM+HLIF
      ISUM=ISUM+1
      GO TO 666
  109 CONTINUE
      NHLLV(I)=NHLLV(I)+ISUM
      HLLV(I)=NHLLV(I)
      CTF(I)=COTVFL(I)*CCOTVF/1000000.
      HLF(I)=HLLVF(I)*CHLLVF/1000000.
      PTV(I)=POTVFL(I)*CPOTVF/1000000.
      PLV(I)=PLVFL(I)*CPLVF/1000000.
      IF(I.EQ.1) GO TO 3001
      IF(NHLLV(I).GE.NHLLV(J)) GO TO 3002
      NHLLV(I)=NHLLV(J)
      HLLV(I)=NHLLV(I)
      HCONST(I)=0.
      GO TO 3003
 3001 CONTINUE
      HCONST(I)=HLLV(I)
      GO TO 3003
 3002 CONTINUE
      HCONST(I)=HLLV(I)-HLLV(J)
 3003 CONTINUE
      VCHLLV(I)=HCONST(I)*CHLLV/1000000.
      IHLCON(I)=HCONST(I)
      COST(I)=CTF(I)+PTV(I)+PLV(I)+HLF(I)+VCCOTV(I)+VCPOTV(I)+VCPLV(I)+
     1VCHLLV(I)
C     ********** TOTAL FLIGHTS DURING SCENARIO**************
      IHLFLT=IHLFLT+NHLLVF(I)
      IPLFLT=IPLFLT+IPLVFL(I)
      IPOFLT=IPOFLT+IPOTVFL(I)
      ICOFLT=ICOFLT+IOTVFL(I)
      TRANS(I)=COST(I)*1000000.
      SPSS(I)=SPSCUM(I)-SPSYR(I)
  101 CONTINUE
      CALL FINANC(GRCCOS,SAT,ASSY,TRANS,SPSS,NYR,POWG)
 8111 FORMAT('*****************'/' TRANSPORTATION INPUT DATA'/12A6/' NYR
     1=',I5,10X,'IYR=',I5,'FUELCO=',F15.2,'COMASS=',F15.2/' FLTMAS=',F15.2,
     2'TLIFE=',F15.2,'FUELPT=',F15.2,'PFLT=',F15.2/' ROTHYR=',F15.2,'POTVP='
     3F15.2,'PTMASS=',F15.2,'HLVPL=',F15.2/' TURNRD=',F15.2,'HLIF=',F15.2,
     4'AVAIL=',F15.2,'OMRAT=',F15.2/' CCOTVF=',F15.2,'CHLLVF=',F15.2,'CPOTVF
     5=',F15.2,'CPLVF=',F15.2/' CCOTV=',F15.2,'CHLLV=',F15.2,'CPOTV=',F15.2,
     6'CPLV=',F15.2/' PLVP=',F15.2,'PLVTR=',F15.2,'VLIFE=',F15.2,'CLIFE='
     7F15.2)
 2001 FORMAT(12A6/' YEAR',2X,'SPS/YR',2X,'SPSCUM')
 2002 FORMAT(I6,2I8)
 2003 FORMAT(12A6)
 2004 FORMAT(1H1)
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 2005 FORMAT(' YEAR',2X,'PERSONNEL',2X,'ROUND TRIPS',2X,'TOTAL SPS MASS
     1IN GEO')
 2006 FORMAT(I5,F11.0,F13.0,F20.0)
 2007 FORMAT(' MASS TO BE CARRIED BY HLLV PER YEAR'/' YEAR',2X,'SPS MAS
     1S',2X,'O/M MASS',2X,'COTV FUEL MASS',2X,'POTV FULL MASS',2X,'COTV
     2VEH MASS ',2X,'POTV VEH MASS ',2X,'ASSEMBLY MACH.',2X,'TOTAL MASS'
     3)
 2008 FORMAT(I5,2F10.0,5F16.0,F12.0)
 7000 FORMAT(' YEAR',2X,'VEHICLE FLIGHTS/YEAR',6X,'VEHICLES CONSTRUCTED/
     1YEAR',2X,'CUMULATIVE NO. OF VEHICLES'/7X,'COTV',2X,'POTV',3X,'PLV'
     2,2X,'HLLV',6X,'COTV',2X,'POTV',3X,'PLV',2X,'HLLV',5X,'COTV',2X,'PO
     3TV',3X,'PLV',2X,'HLLV')
 7001 FORMAT(I5,4I6,4X,4I6,3X,4I6)
 9500 FORMAT(' TOTAL FLIGHTS'/' COTV='I6/' POTV='I6/'  PLV='I6/' HLLV='I
     16)
 7002 FORMAT(' YEAR',7X,'FLIGHT COST PER YEAR MILLIONS OF DOLLARS',3X,'V
     1EHICLE COST PER YEAR MILLIONS OF DOLLARS',4X,'TOTAL COST'/10X,'COT
     2V',6X,'POTV',7X,'PLV',6X,'HLLV',6X,'COTV',6X,'POTV',7X,'PLV',6X,'HL
     2LV')
 7003 FORMAT(I5,2X,8F10.0,F18.0)
 2888 FORMAT('****************'/' SATELLITE INPUT DATA'/' UNITM='E16.8,8X
     1,'GROWF='E16.8/8X,'COMPONENT MASSES',10X,'COST ESTIMATING RATIOS'/
     2' SCELLM='E16.8,10X,'SCELLC='E16.8/'  CONCM='E16.8,10X,' CONCC='
     3E16.8/' STRUCM='E16.8,10X,'STRUCC='E16.8/' PDISTM='E16.8,10X,'PDIS
     4TC='E16.8/'  GENRM='E16.8,10X,' GENRC='E16.8/'  WAGDM='E16.8,10X,
     5' WAGDC='E16.8/' ASTRLM='E16.8,10X,'ASTRUC='E16.8/' ADISTM='E16.8,
     610X,'ADISTC='E16.8/' RJOINM='E16.8,10X,'RJOINC='E16.8/'  PCONM='
     7E16.8,10X,' PCONC='E16.8/' FOINTM='E16.8,10X,'FOINTC='E16.8/' OTHE
     8RM='E16.8,10X,'OTHERC='E16.8)
 2890 FORMAT('*************************'/' GROUND SYSTEM INPUT DATA'/
     1' A='F10.2,5X,' B='F10.2,5X,' S='F10.2,5X,' LAND='F10.2,5X,' PREP=
     1'F10.2/' POW='F10.2,5X,'GMATER='F10.2,5X,'ZONE='F10.2)
 2898 FORMAT(' ELEMT='E15.8,' CELEMT='E15.8)
 2891 FORMAT('**************'/' ASSEMBLY SYSTEM INPUT DATA'/6X,' NO. OF
     1MACHINES',6X,'UNIT MASS MT',10X,'COST /MT   '/' BBMN='E14.6,' UBBM=
     2'F12.4,' CLBM='E15.6/' CRMN='E15.6,' UCRM='F12.4,' CCRM='E15.6/
     3' CELINN='E14.6,'UCELIN='F12.4,'CCELIN='E15.6/' REFLIN='E14.6,
     4'UREFLI='F12.4,'CREFLI='E14.6/' DHIN='E15.6,' UDHI='F12.4,' CDHI='
     5E14.6/' AMMN='E15.6,' UAMM='F12.4,' CAMM='E15.6/' FAMN='E15.6,
     6' UFAM='F12.4,' CFAM='E15.6/' SUBINN='E14.6,'USUBIN='F12.4,'CSUBIN
     7='E14.6/'**********'/' PLEO='F10.2,5X,'CLEO='F10.2,5X,'CGEO='F10.2
     8,5X,'CGEO='F10.2)
      WRITE(6,2004)
      WRITE(6,2001) TITLE
      DO 102 I=1,NYR
      WRITE(6,2002) IYEAR(I),ISPSYR(I),ISPSCL(I)
  102 CONTINUE
      WRITE(6,2004)
      WRITE(6,7000)
      DO 8000 I=1,NYR
      WRITE(6,7001)IYEAR(I),IOTVFL(I),IPOTVF(I),IPLVFL(I),NHLLVF(I),
     1ICVCON(I),IPVCON(I),IPLCON(I),IHLCON(I),NCOTV(I),NPOTV(I),
     2NPLV(I),NHLLV(I)
 8000 CONTINUE
      WRITE(6,9500) ICOFLT,IPOFLT,IPLFLT,IHLFLT
      WRITE(6,2004)
      WRITE(6,2007)
```

```
01073                  DO 114 I=1,NYR                                                   002035
01100                  WRITE(6,2008) IYEAR(I),SPSMAS(I),OM(I),COTVFU(I),POTVFU(I),      002035
01103                 1COTVMA(I),POTVWT(I),WT(I),HLLVM(I)                               002035
01113          114     CONTINUE                                                         002053
01115                  WRITE(6,2004)                                                    002053
01117                  WRITE(6,2005)                                                    002060
01121                  DO 103 I=1,NYR                                                   002070
01124                  WRITE(6,2006) IYEAR(I),PCEO(I),RTGEO(I),SPSGEO(I)                002070
01132          103     CONTINUE                                                         002101
01134                  WRITE(6,2004)                                                    002101
01136                  WRITE(6,7002)                                                    002116
01140                  DO 8001 I=1,NYR                                                  002116
01143                  WRITE(6,7003) IYEAR(I),CTF(I),PTV(I),PLV(I),HLF(I),VCCOTV(I),    002116
01143                 1VCPOTV(I),VCPLV(I),VCHLLV(I),COST(I)                             002116
01157          8001    CONTINUE                                                         002135
01161                  GO TO 1                                                          002135
01162                  END                                                              002140
```

END OF COMPILATION: NO DIAGNOSTICS.

```
@FOR,IS FINANC,FINANC
FOR S1E3-04/25/77-15:51:24 (,0)

   SUBROUTINE FINANC     ENTRY POINT 000374

   STORAGE USED: CODE(1) 000424; DATA(0) 000717; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   NRNL$
    0004   XPRR
    0005   NWDU$
    0006   NI02$
    0007   XPRI
    0010   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000032 117G      0001     000121 152G      0001     000170 173G      0000     000555 1776F     0000     000552 1777F
    0001     000033 1778F     0000     000575 178CF     0001     000140 243G      0001     000174 6L0L      0001     000305 IC3L
    0001     000120 699L      0001     000230 866L      0000     000071 901F      0000 R   000000 COS       0000 R   000472 COUNT
    0000 R   000520 IDTE      0000 R   000466 DELR      0000 R   000503 DFLTA     0000     000504 FINAN     0000 R   000461 CENIN
    0000 R   000501 GRCOS     0000 I   000470 I         0000 R   000463 INC       0000 R   000001 INCOME    0000 R   000464 INFLP
    0000 R   000460 INJPS     0000 R   000465 INTR      0000 I   000475 ITIME     0000 R   000150 OM        0000 R   000467 CMR
    0000 R   000462 CPPINF    0000 R   000473 OUT       0000 R   000464 PF        0000 R   000460 PTAXR     0000 R   000466 FATE
    0000 R   000463 ROR       0000 R   000502 SPSCOS    0000 R   000376 SPSCUM    0000 R   000066 TAX       0000 R   000471 TCOTE
    0000 R   000470 TIME      0000 R   000314 TOTAL     0000 R   000232 TOTEXP    0000 R   000474 TSUM      0000 R   000477 ITIME

00100   *DIAGNOSTIC*  THE VARIABLE, SPSCUM, IS REFERENCED IN THIS PROGRAM, BUT IS NOWHERE ASSIGNED A VALUE.
00101        1*             SUBROUTINE FINANC(GRDCOS,SPS,ASSY,TRANS,SPSS,NYR,PUNG)               000001
00103        2*             REAL INCOME,INC,INFLP,INTR                                            000001
00104        3*             DIMENSION TAX(50),GRDCOS(50),CM(50),SPS(50),TOTEXP(50),ASSY(50),      000001
00104        4*            1TRANS(50),TOTAL(50),INCOME(50),SPSCUM(50)                             000001
00105        5*             DIMENSION SPSS(50)                                                    000001
00106        6*             NAMELIST/FINAN/PTAXR,GENINF,OPPINF,ROR,INFLP,PF,DELR,RATE,OMR,INTR    000001
00106        7*            1,TIME,TCOTE                                                           000001
00106        8*       C     GRDCOS,COST OF GROUND SYSTEM                                          000001
00106        9*       C     PTAXR,AD VALOREM TAX RATE                                             000001
00106       10*       C     GENINF,GENERAL INFLATION RATE                                         000001
00106       11*       C     SPS,SPS COST                                                          000001
00106       12*       C     OMR,O/M RATE                                                          000001
00106       13*       C     OPPINF,OPERATION INFLATION RATE                                       000001
00106       14*       C     TOTEXP,TOTAL COST(GROUND,TRANSPORT,SATELLITE,ASSEMBLY)                000001
00106       15*       C     ROR,RATE OF RETURN                                                    000001
00106       16*       C     PF,PLANT FACTOR                                                       000001
00106       17*       C     RATE,MILLS/KWH                                                        000001
00106       18*       C     INFLP,INFLATION RATE FOR POWER                                        000001
00106       19*       C     ASSY,ASSEMBLY COST                                                    000001
00106       20*       C     TRANS,TRANSPORTATION COST                                             000001
00106       21*       C     DELR,DELTA RATE                                                       000001
```

X-APP-B-14

```
      COUNT=0.
      OUT=0.
      READ(5,FINAN)
      TSUM=0.0
      ITIME=TIME
      DO 199 I=1,ITIME
      TTIME=I
      DDTE=TDDTE/TIME*(1.+INTR)**(TIME-TTIME)
      TSUM=TSUM+DDTE
199   CONTINUE
      DDTE=TSUM
      WRITE(6,1777)
      WRITE(6,1780)PTAXR,GENINF,OPPINF,ROR,INFLP,PF,DELR,RATE,OMR
     1,TDDTE,TIME,INTR
      WRITE(6,1777)
      DO 111 I=1,NYR
      WRITE(6,1778) GRDCOS(I),SPS(I),ASSY(I),TRANS(I),SPSCUM(I)
111   CONTINUE
600   CONTINUE
      COS=0.
      INC=0.
      GRCOS=0.
      SPSCOS=0.
      DO 601 I=1,NYR
C     ******COST******
      GRCOS=GRDCOS(I)+GRCOS
      SPSCOS=SPS(I)+SPSCOS
      TAX(I)=(GRCOS*PTAXR)*(1.+GENINF)**I
      OM(I)=(SPSCOS+GRCOS)*OMR*(1.+OPPINF)**I
      TOTEXP(I)=(GRDCOS(I)+SPS(I)+ASSY(I)+TRANS(I))*(1.+GENINF)**I
      TOTAL(I)=TAX(I)+OM(I)+TOTEXP(I)
      IF(I.NE.1) GO TO 886
      TOTAL(I)=TOTAL(I)+DDTE
886   CONTINUE
      COS=TOTAL(I)*(1./(1.+ROR)**I)+COS
C     ******INCOME******
      INCOME(I)=POWG      *8760.*PF*SPSS(I)*RATE*(1.+INFLP)**I
      INC=INCOME(I)*(1./(1.+ROR)**I)+INC
601   CONTINUE
      COUNT=COUNT+1.
      DELTA=INC-COS
      IF(DELTA.GE.0.) GO TO 603
      RATE=RATE+DELR
      GO TO 600
603   CONTINUE
      IF(OUT.NE.0.) GO TO 699
      RATE=RATE-DELR
      DELR=DELR/100.
      OUT=1.
      GO TO 600
699   CONTINUE
      WRITE(6,1777)
      WRITE(6,1776) COUNT,COS,INC,RATE
      DO 605 I=1,NYR
      WRITE(6,1778) TAX(I),OM(I),TOTEXP(I),TOTAL(I),INCOME(I)
605   CONTINUE
1777  FORMAT(1H1)
```

```
00257      79*       1778 FORMAT(E20.8)                                                                          000352
00260      80*       1776 FORMAT(' COUNT=',F10.0/' COST=',E15.6/' INCOME=',E15.6/' RATE=',E15.6)                000352
00261      81*       901  FORMAT(I3,7E16.8/3X,2E16.8)                                                            000352
00262      82*       1780 FORMAT('****************'/' FINANCIAL INPUT DATA'/' PTAXR=',F15.4/                      000352
00262      83*          1' GENINF=',F15.4/' OPPINF=',F15.4/'    RCR=',F15.4/'  INFLF=',F15.4/                     000352
00262      84*          2'     PF=',F15.4/'  DELR=',F15.4/'  RATE=',F15.4/'    OMR=',F15.4/                       000352
00262      85*          3'  TDCTE=',E16.8/'  TIMI=',F15.4/'  INIR=',F15.4)                                        000352
00263      86*           RETURN                                                                                  000352
00264      87*           END                                                                                     000423

     END OF COMPILATION:          1 DIAGNOSTICS.

@XQT
MAP27.1 RL71-3 04/25/77 15:52:23

ADDRESS LIMITS     001000 016531        7002 IBANK WORDS DECIMAL
                   040000 055406        6915 DBANK WORDS DECIMAL
STARTING ADDRESS   014371

              SEGMENT $MAIN$          001000 016531      040000 055406

NSWTC$/FOR69               $(1)     001000 001024
NRBLK$/FOR-E2              $(1)     001025 001047
NRWND$/FOR-E3              $(1)     001050 001133      $(2)      040000 040011
NWEF$/FOR-E2               $(1)     001134 001341      $(2)      040012 040031
NSCLS$/FOR-E3              $(1)     001342 001472      $(2)      040032 040107
NFTCH$/FOR-E2              $(1)     001473 001755      $(2)      040110 040123
NFTVS$/FOR-E2              $(1)     001756 002000
NCLOS$/FOR-E3              $(1)     002001 002236      $(2)      040124 040151
NWBLK$/FOR68               $(1)     002237 002350
NMSPL$/FOR-E3              $(1)     002351 002405
NUPDA$/FOR68               $(1)     002406 002441
NRF...3                                                $(2)      040152 042377
NOTIN$/FOR-E3              $(1)     002442 002736      $(2)      042400 042403
NOUT$/FOR-E3-LPE           $(1)     002737 004452      $(2)      042404 042445
NCNVT$/FOR68               $(1)     004453 004674      $(2)      042446 042542
NIOER$/FOR-E3              $(1)     004675 005114      $(2)      042543 042712
NININ$/FOR-E3              $(1)     005115 005352      $(2)      042713 042714
NINPT$/FOR-E3              $(1)     005353 006744      $(2)      042715 042750
NFMT$/FOR-E3               $(1)     006745 007627      $(2)      042751 043025
NFCHK$/FOR-E3              $(1)     007630 010621      $(2)      043026 043176
                           $(3)     010622 010622      $(4)      043177 043250
NTABS/E3-JSC                                           $(2)      043251 043310
FORCOM$/FORFTN                                         $(2)      043311 043316
NERCOM$/FOR-TE3            $(1)     010623 010702      $(2)      043317 043332
FORVCOM$/FOR-TE1                                       $(2)      043333 043342
NERR$/FOR-E3               $(1)     010703 011244      $(2)      043343 043522
NEXP5$/FOR68               $(1)     011245 011332      $(2)      043523 043532
NEXP6$/FOR-E3              $(1)     011333 011530      $(2)      043533 043604
NSTOP$/FORE3-RLIB          $(1)     011531 011630      $(2)      043605 043656
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NOBUF$/FOR68                  $(1)    011631 011671
NLINP$/FOR-E3                 $(1)    011672 013450   $(2)    043657 044046
NIERS/FOR-E3                  $(1)    013451 013627   $(2)    044047 044166
NIBUF$/FOR-E2                 $(1)    013630 013667   $(2)    044167 044167
NINTR$/FORE3-RLIB             $(1)    013670 013744   $(2)    044170 044205
BLANK$COMMON(COMMO+BLOCK)
FINANC                        $(1)    013745 014370   $(0)    044206 045124
                                                      $(2)    BLANK$COMMON
COST                          $(1)    014371 016531   $(0)    045125 055406
                                                      $(2)    BLANK$COMMON

SYS$*RLIB$. LEVEL 71-3
END MAP
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Tony E. Redding
James O. Rippey
Harmon L. Roberts
Systems Evaluation Off.

XI. COMPARISONS WITH ALTERNATE SYSTEMS

A. SUMMARY

To become a viable electrical power source for the future, SPS must be competitive with alternative sources from the standpoint of cost, tech-status, and environmental factors. Studies have been conducted to determine current and projected cost of electricity for fossil, nuclear, solar (ground), geothermal, ocean thermal, and hydroelectric power systems. Also, environmental factors such as land use, water consumption and air pollution have been determined for comparable size alternative systems. The evaluation of current and projected technology status of each of the systems indicated an anticipated shift in power source mix from predominantly fossil fuel to predominantly nuclear power by 2000. The study also showed the potential emergence of new technology in solar and geothermal energy.

To the depth studied, the SPS appears to be competitive with alternative systems for the future, particularly fuel-burning systems for which fuel cost may undergo higher-than-average inflation. From an economic standpoint, geothermal power appears very attractive; however, its widespread use may be limited by environmental considerations and the lack of suitable plant sites. SPS offers the environmental advantage of no major cooling water requirements.

B. STUDY APPROACH

The approach utilized in this study was to first review and update electrical energy demand projections from JSC's previous SPS study (ref. 1) and to identify the potential competitive power source technologies that could be utilized to meet this demand. Only those technologies suited for large-scale, baseload power generation were considered applicable; however, systems not normally considered baseload types, such as wind power and hydroelectric were included for reference purposes. The time period of interest is 1995 to 2025; therefore, virtually all of the presently known power system concepts are potential sources, including those systems which utilize fossil fuels. Data describing the economic, environmental, and technology status were then developed for each system. The economic comparator utilized was cost of electricity (mills/kwh) at the busbar.

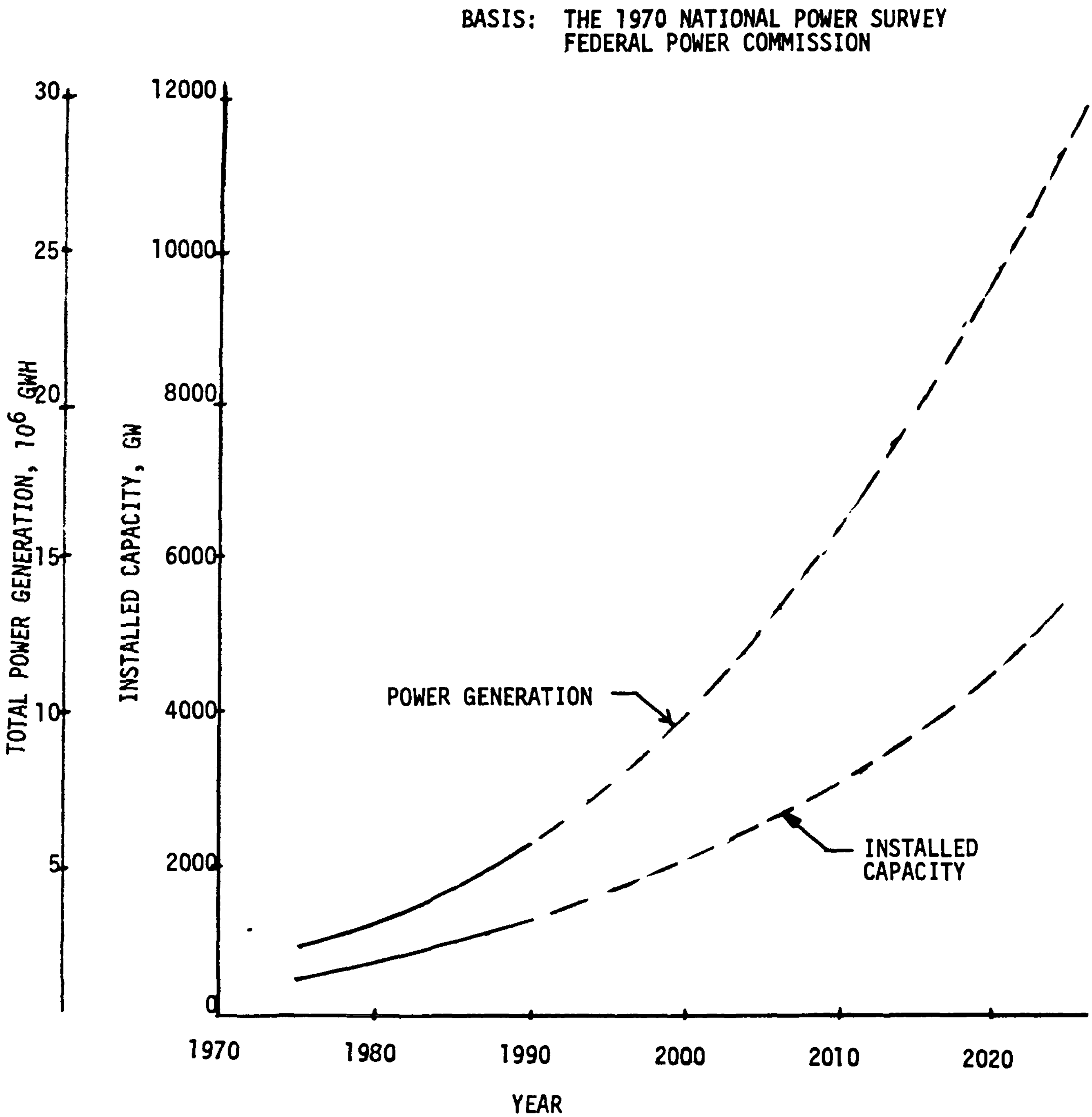
Environmental considerations included were land use, air pollution water requirements, and waste disposal requirements. Technological comparisons were made on the basis of current status, expected commercial date, economic size, key problems, and potential and/or anticipated contribution to the electrical energy supply in the year 2000.

C. ELECTRICAL ENERGY REQUIREMENTS PROJECTED DEMAND

JSC's previous in-house SPS study (ref. 1) included a projection of the Nation's electrical energy requirements through the year 2025. This projection (shown in figure XI-C-1) was based on Federal Power Commission projection through 1990 with an extrapolation to the year 2025. Figure III-A-2 (section III) shows projections of electrical energy requirements made by the Department of Interior, Shell, Electrical World Magazine, and ERDA. These projections are somewhat lower than the extrapolated FPC projection; however, the extrapolated FPC projection appears to be a reasonable upper-limit on future electrical energy demand. Figure III-A-3 shows ERDA projections of electrical capacity requirements through the year 2025. These projections are discussed in more detail in section III of this report.

D. SOURCE MIX PROJECTIONS

Figure XI-D-1 shows two projections of power source utilization in the future. The solid line is the projection used in ref. 1. The Department of Interior projection shows higher use of coal through the 1980's and 1990's and less use of nuclear power; however, by 2000, the use of these primary energy sources is about the same as the original FPC projection. Only conventional energy systems are included in these projections although it is expected that the new-technology systems will be utilized to various levels by the year 2000.

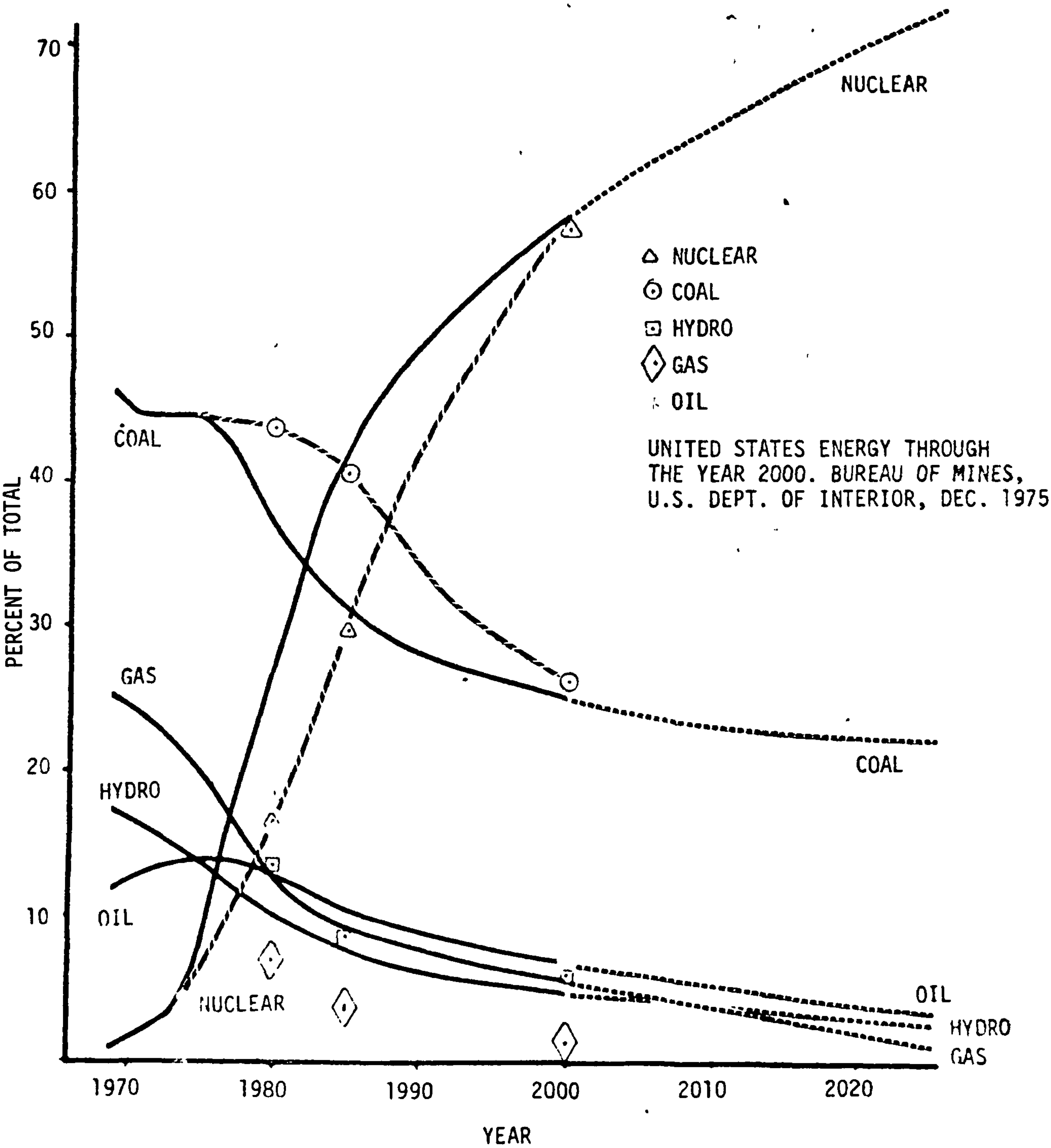


TOTAL ELECTRICAL POWER GENERATION
AND INSTALLED CAPACITY PROJECTIONS

Figure XI-C-1

JSC-EZ-75-12019

Figure XI-D-1
ELECTRICAL ENERGY RESOURCE UTILIZATION



E. ALTERNATIVE POWER SYSTEM TECHNOLOGIES

A review of the literature indicates a large number of existing and potential power system alternatives that may be contemporary with SPS. Figure XI-E-1 shows a list of those technologies selected for evaluation in this study. The list includes proven technology systems in current widespread use and new technology concepts under active development by government or industry. Each of these technologies are discussed in detail in the sections which follow.

1. Conventional Systems

a. NATURAL GAS: Early use of gaseous fuels were localized (northeast primarily) and many utilities distributed gas manufactured from coal. It was used primarily for space heating, water heating, and cooking, but not for power generation. In 1947, a major change occurred in the gas industry when natural gas from the southwest was piped to the east coast through two converted liquid pipelines, the "Big Inch" and the "Little Inch." The "Big Inch" had been used for crude oil transmission and the "Little Inch" was a refined oil pipeline. As a result, the use of natural gas was expanded to all end-use classifications, including power generation. By 1974, about 17 percent of the total U. S. power generation was derived from natural gas. In 1970, about 270,000 miles of high-pressure gas transmission network existed in the lower 48 states. This system included about 4 million horsepower of compression. Due to substantial reduction in gas supply, the pattern of rapid expansion that occurred in the gas industry in the 50's and 60's may soon drastically change. Already, power utilities in the southwest are planning a shift from natural gas system to coal, oil, and nuclear. For example, in 1970 almost 100 percent of the power generated in Texas was produced by natural gas-fired powerplants. By 1975, this had dropped to 90 percent with the other 10 percent split evenly between fuel oil and lignite. It is expected that by 1980, natural gas will be used to produce 55 percent of the power, and by 2000 only 3 percent. Figure XI-E-2 shows a schematic diagram of a typical natural gas-fired power plant.

Figure XI-E-3 shows a diagram of the natural gas use chain beginning with exploration for the resource. As indicated in the diagram, the natural gas may be used in a central station powerplant with 35 to 50 percent conversion efficiency or on-site generation with heat recovery. In both cases, residual heat must be rejected to the environment. In the case of a central station plant, the heat is rejected either to a local body of water (lake, river, ocean) or through a wet or dry cooling tower. Wet cooling towers provide for the highest overall efficiency, but require large quantities of water for evaporation and other losses. A typical 1000 Mwe natural gas power plant using a cooling pond heat sink requires about 13 billion gallons of makeup water per year. This amount of water is roughly equivalent to the needs of a city of 150,000 population.

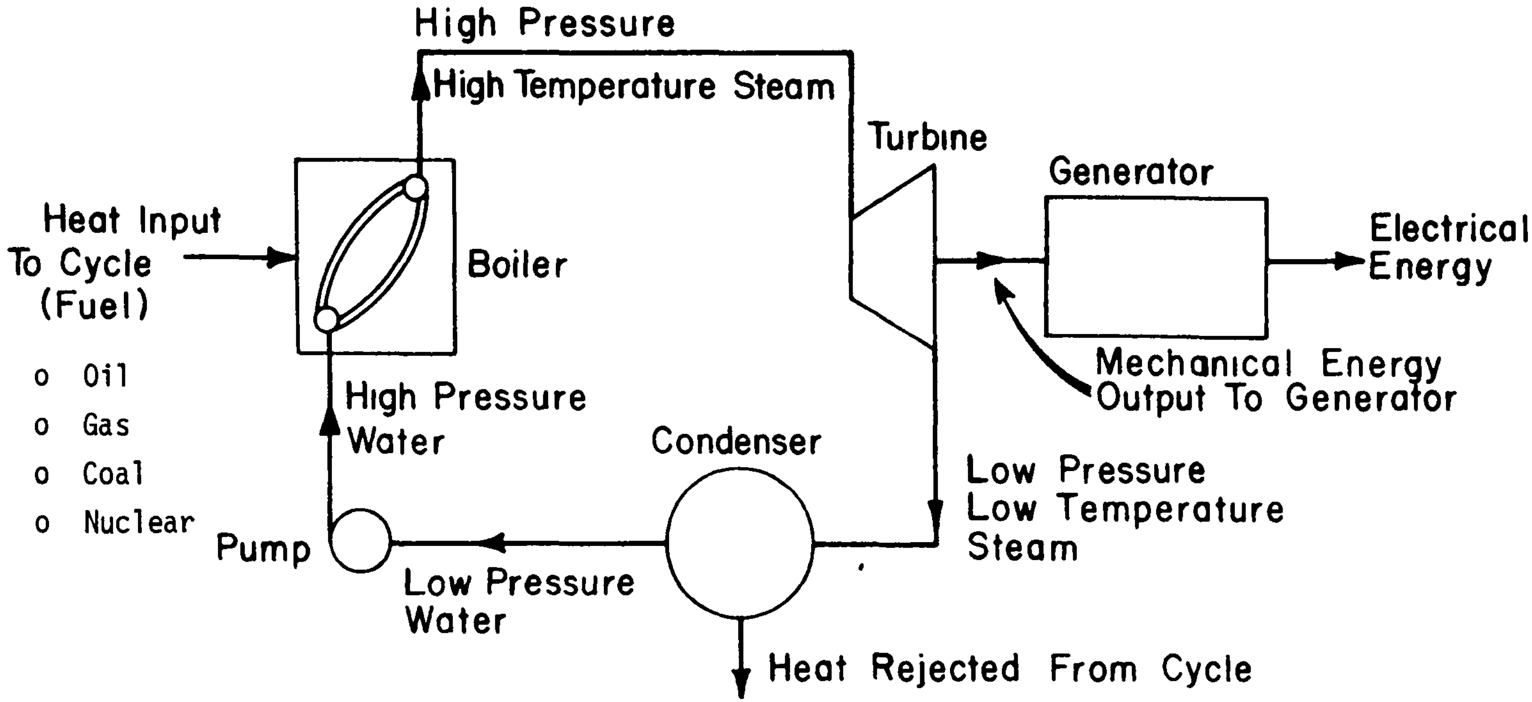
CONVENTIONAL SYSTEMS	% OF 1975 GENERATION
NATURAL GAS	17
OIL	18
COAL	44
NUCLEAR FISSION	6
HYDROELECTRIC	15

ADVANCED

- NUCLEAR FISSION (BREEDER)
- FUSION
- SOLAR (TERRESTRIAL, SPACE)
- GEOTHERMAL
- OCEAN THERMAL
- WIND
- OIL SHALE
- BIOCONVERSION

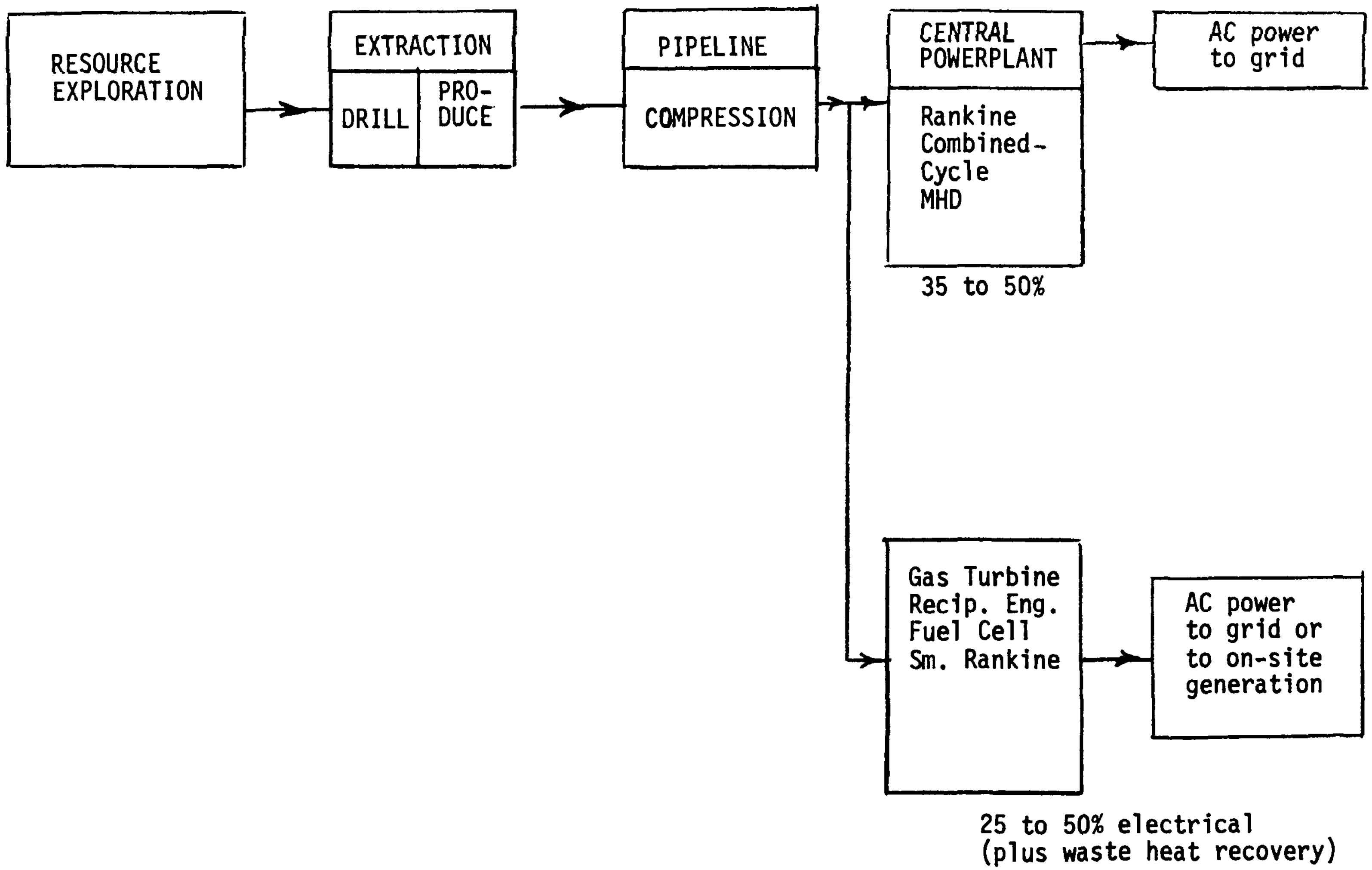
ALTERNATE POWER SYSTEMS

FIGURE XI-E-1



Simplified Schematic of a Steam Power Plant

Figure XI-E-2



Natural Gas Utilization for Power Generation and Efficiencies

Figure XI-E-3

Technology Status: Natural gas energy systems are generally proven technology with the exception of extraction technology and some end-use technologies such as fuel cells. ERDA plans to spend approximately 30 million dollars in FY77 on improved oil and gas extraction technology.

Environmental Considerations: Natural gas production, transmission and utilization is environmentally a very clear process. Some thermal pollution and water pollution problems occur at natural gas processing plants (sulfur removal), but these are relatively minor. Likewise, air pollution is minor except for NO_x emission from thermal powerplants and engines which drive gas transmission compressors.

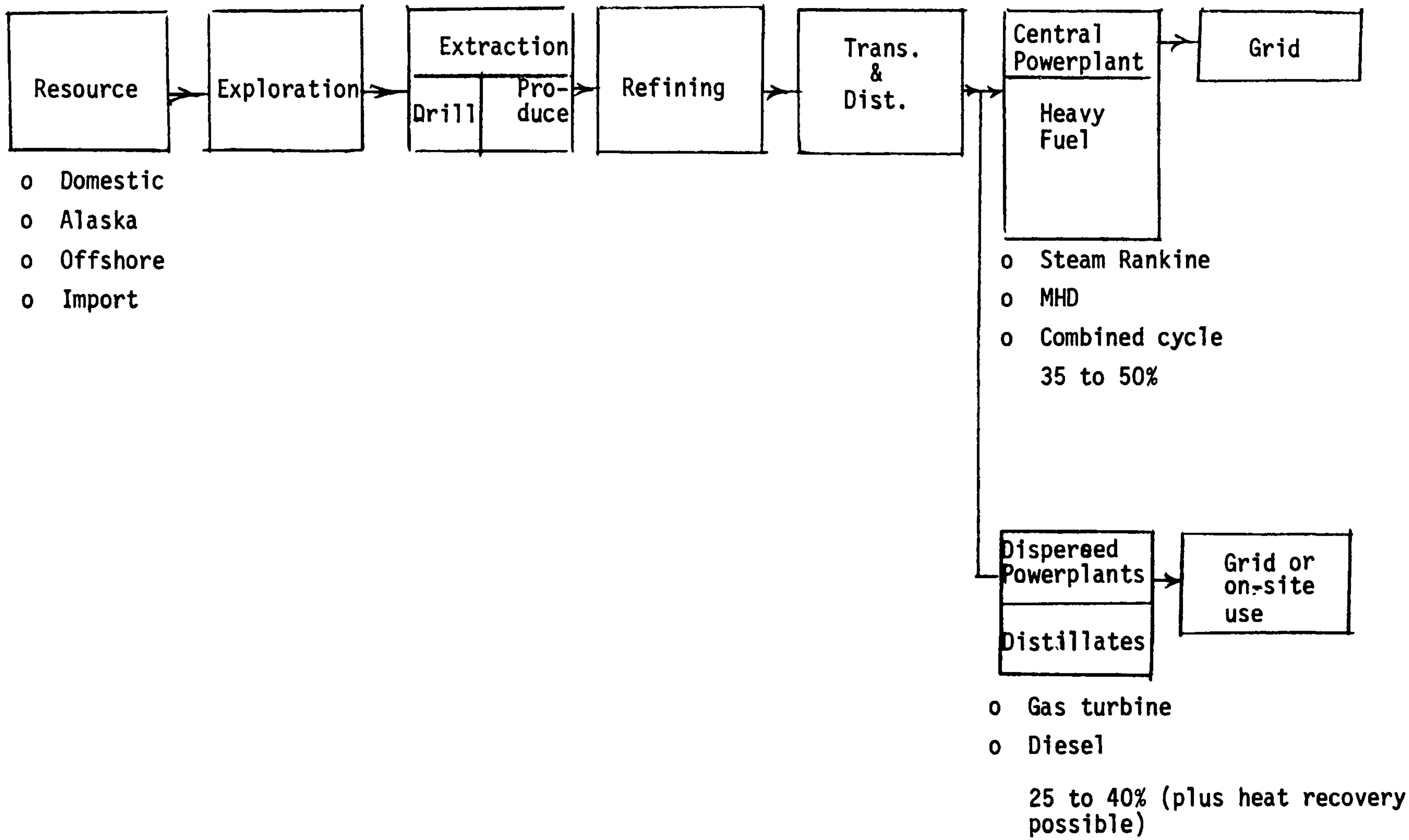
Economic Considerations: The economics of power generation using natural gas-fired systems has been strongly tied to government regulated wellhead gas prices. As intrastate prices are raised and as deregulation of interstate gas occurs, more gas will be diverted from boiler fuel end-use to residential, commercial and industrial heating and product uses. Powerplant capital costs tend to be low for natural gas-fired systems because of no fuel handling and storage costs and relatively simple combustion systems. Maintenance costs are also low because of the purity of the pipeline gas and clean burning characteristics of the fuel.

From an economic standpoint, the key problems with natural gas fueled systems are increasing fuel costs and availability and reliability of supply.

Projections: Most projections indicate a rapid reduction in the use of natural gas for power generation in the late 70's and 80's and, by 2000, only one to five percent of the power generation will be natural gas derived.

b. OIL: Oil has been a significant factor in our national growth and development. Oil is a primary energy source in all end-use categories (transportation, power generation, etc.). The United States was a net oil exporter until 1948, when U. S. consumption exceeded supply for the first time. Although the importation of oil creates political and economic problems, it will probably continue for many years.

At present, about 18 percent of the power generated in the U. S. is derived from oil-fired systems, primarily boiler-fired steam turbine-generator plants. Figure XI-E-2 shows a schematic diagram of a typical oil-fired steam power plant. Figure XI-E-5 shows a schematic diagram of the utilization chain from basic resource to electrical energy to the user. Like natural gas, fuel oil may be used either in a central station power plant or in smaller, on-site powerplants. Oil has the advantage of relatively inexpensive storage, whereas gas storage must be accomplished on a large scale (salt domes, depleted oil fields, etc.) to be economical.



Fuel Oil Utilization for
Power Generation and Efficiencies

Figure XI-E-5

Technology Status: The technology of fuel oil exploration, extraction, distribution, and utilization for power generation closely parallels that of natural gas. The only major difference is the refining processes which convert crude oil into many varieties of fuels and other products. Oil transmission technology has been mostly expanded by the advent of the Alaskan pipeline.

Environmental Considerations: The most serious environmental consideration associated with oil extraction is well blowouts. Although the number of blowouts per year is small (0.04 to 0.2 percent of the new wells started), the contamination and damage is usually severe, particularly if a fire is involved. The most serious environmental concern in oil transport is spills, particularly from ocean-going tankers.

Air pollution is a major concern in oil-fired systems, especially where high sulfur oil is used directly in boilers. NO_x production is also a major consideration, but particulates, CO, and other organics pollution is not as great a concern as with coal.

Economic Considerations: The economics of fuel oil burning systems is driven by oil cost and supply considerations. At $12 per bbl, the cost of electricity for fuel only is about 22 mills/kwh. Imported oil currently costs from about $13 to $15/bbl, depending on quality and other factors. The capital cost of boiler plants and engines which use oil are reasonably low and tend to be predictable. Multi-megawatt oil-fired steam powerplants cost from 290 to 350 $/kw installed (1976). Gas turbine and large diesel electric systems cost from $100 to $250/kw installed.

Projection: With the continued high demand for oil for transportation and other non-power generation requirements, few oil-fired powerplants will be installed or replaced in the future. It is estimated that by 2000, only 6 to 8 percent of the U. S. electrical energy production will be derived from oil, down from 18 percent in 1974.

c. COAL: Coal was the primary energy source in the United States from the early 1880's until shortly after World War II. Since that time, a number of major users have converted to oil or natural gas as these fuels became available at competitive prices. Railroads converted to diesel oil and residential and commercial converted to oil and gas. Electric utilities also moved to the use of cleaner burning oil and gas in the 1960's. These newer fuels were generally cleaner, easier to handle, and more environmentally acceptable than coal. It is expected that this trend will be reversed as a result of natural gas supply problems and oil importation (high cost) considerations.

Technology Status: The coal utilization technology is expanding rapidly at the present time. Many new developments are in progress in mining, gasification, liquefaction, pollution control, direct-firing, and transport. The most efficient method of coal use for power generation is direct boiler-firing of solid coal (usually pulverized) in a steam power plant as depicted in figure XI-E-2. Overall conversion efficiencies range

from 35 to 40 percent with current technology. The various gasification and liquefaction processes renders the fuel more easily handled, and usually cleaner burning, but a 30 to 50 percent energy loss is taken in the process. Energy conversion efficiencies in direct-fired systems may be increased to 45 to 50 percent with advances in boiler design (fluidized bed), high temperature combined cycles, and, possibly, magetohydro dynamic (MHD) conversion.

Environmental Considerations: Environmental issues exist in practically all steps of coal utilization for power generation. Whether surface mined or underground mined, air, water and solid waste pollution must be dealt with to various degrees.

In the case of surface strip mining, land spoilage is a majcr concern; however, reclamation methods have been developed to negate any long term spoilage. Coal transportation poses problems of numerous trains crossing the country. Use of coal slurry pipelines could ease this problem; however, legal barriers (right-of-way) to their construction must be overcome. Sulfur is the major impurity in coal that causes environmental problems. Sulfur content varies from 0.02 to 7 percent according to geographic location. Low sulfur coal (less than one percent) is generally located in the western United States. The lower heating value (BTU/lb.) of western coal is lower than eastern coals, therefore, the difference between eastern and western coals in terms of amount of sulfur per BTU input is somewhat diminished.

The combustion of coal in boiler plants may produce large quantities of particulates, nitrogen oxides (NO_x) and sulfur oxides (SO_x). Stack gas scrubbers of several types are being developed for SO_x removal; however, the system adds substantially to the cost of the powerplant. Also, the wet scrubber systems that use limestone slurry have major waste disposal problems. Particulates are removed mechanically (cyclone separators), electrostatically (precipitators), or to a limited extent, as part of the SO_x removal.

Coal gasification and/or liquefaction plants have many of the same environmental concerns that exist in direct-fired powerplants. As mentioned earlier, a large energy loss occurs in these processes, requiring more solid fuel input for the same output at the gas or oil-fired powerplants.

Another related consideration in coal energy utilization is mine worker safety. This consideration is most critical for underground operations rather than surface mining.

Economic Considerations: The current cost of electricity derived from coal is about 15 to 26 mills/kwh. The lower cost range applies in location where coal prices are $15 to $20/ton and plant capital costs are $400 to $500/kw installed. The higher cost range is associated with $25 to $30/ton coal and $500 to $600/kw plant costs where stack gas scrubbers

are installed. Stack gas cleanup systems may add as much as 10 to 20 percent to the capital cost of coal-fired powerplant.

An extensive study of advanced energy conversion systems using coal-derived fuels has been recently completed by NASA Lewis Research Center for ERDA and NSF (ref. 9). The study investigated the technical and economic characteristics of the following advanced energy conversion concepts:

a. Advanced steam (Rankine cycle).
b. Open-cycle gas turbine (gasified coal).
c. Closed-cycle gas turbine.
d. Open-cycle magetohydrodynamics (MHD).
e. Closed-cycle MHD.
f. Liquid metal MHD.
g. Super critical carbon dioxide.
h. Liquid-metal Rankine (potassium).
i. Fuel cells (gasified coal).
j. Combined cycle (gas turbine and steam).

The study results showed a wide range of costs of electricity* for the various concepts. The lowest cost systems tended to be the least efficient systems. For example, the cost of electricity for combined cycle systems was 23 to 34 mills/kwh (mid 1974 $), but efficiencies were as low as 20 percent. On the other hand, MHD concepts had efficiencies of up to 54 percent, but electricity costs were up to 110 mills/kwh. These high costs are attributable to high capital costs for the power conversion system and high balance-of-plant costs.

<u>Projections</u>: Coal is presently used to produce about 44 percent of the nations total electrical energy. This percentage is expected to decrease to about 25 percent by 2000; however, coal will comprise about 78 percent of the fossil fuel input to electrical power production by 2000. This is compared to about 56 percent presently. The projected use of coal for power generation seems to be subject to progress of other technologies such as the liquid-metal fast breeder reactor (LMFBR) and, to a lesser extent, solar power. If these other technologies are developed in a timely fashion and are economical, they will probably be used in lieu of coal to avoid the environmental, institutional and resource limitation constraints associated with coal use.

The total remaining U. S. coal resources are about 3000 billions of short tons. Only about one-half of this quantity is known to exist (discovered). The remaining half is yet undiscovered, but nevertheless, believed to exist based on broad geological knowledge and theory. Of the discovered quantity, only about 200 billion tons are classified as reserves, meaning they are known in location and quantity and economically recoverable using currently available technology.

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*Busbar cost, transmission and distribution not included.

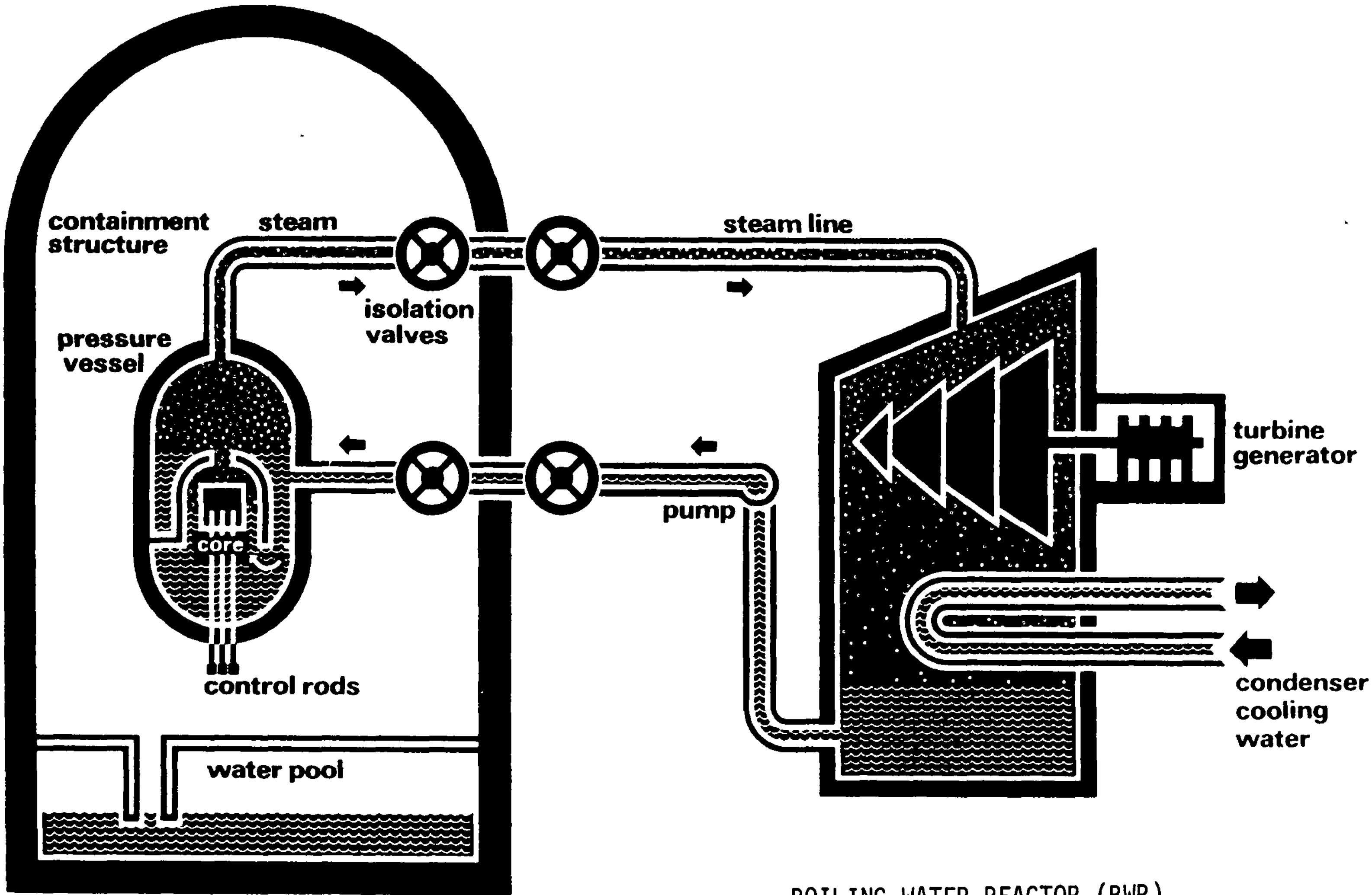
Another factor that will tend to restrain coal use will be raising the necessary capital to obtain requisite coal mines. Most of the coal presently mined is on privately owned land, although almost 50 percent of the coal land is federally owned. With high demand for coal, the mine lease and purchase costs are apt to greatly increase in the future.

d. NUCLEAR FISSION: Nuclear fission reactor power plants may be classified as either "burner" or "breeder" type reactors. Burner reactors generally operate on thermal or "slow" neutrons which cause fissioning of uranium 235 atoms. The energy released in this fission process is approximately 1000 kw of thermal energy (heat) per gram of U-235 fissioned (consumed) per day. Thermal neutrons are produced by a moderator or "slowing down" material within the reactor. Water (light or heavy) and carbon are good moderator materials. The process is controlled by inserting or withdrawing neutron absorber materials (control rods) from the reactor core, thus controlling the neutron population at a given time. Compounds containing boron make good neutron absorber materials. The heat generated in the reactor is transferred to a coolant which conveys the energy to a steam generator. The steam is used to generate electricity via a convectional steam turbine system as indicated in figure XI-E-2.

Breeder reactors will produce more fissionable material than it actually consumes during its operation. This seemingly impossible process occurs as follows:

In a water cooled, burner reactor, a neutron is either absorbed by or splits a uranium-238 atom during its chain reaction. Absorbed neutrons cause the uranium isotope to convert into plutonium-239, which can spontaneously emit its own neutrons. A breeder reactor may use a fuel mixture of uranium-238, which is found in nature, and plutonium-239, which can be obtained from a previously operated burner reactor. A chain reaction in the breeder is started by neutrons being emitted from the plutonium. The neutrons are either absorbed by, or split, the uranium atoms. The splitting atoms will, in turn, emit some of their own neutrons and maintain the chain reaction, while absorbed neutrons will convert uranium atoms into more plutonium. As the chain reaction continues, more plutonium is produced than is actually consumed. Unlike the burner reactor, the breeder reactor does not utilize a moderator material but operates on "fast" neutrons. Otherwise, the breeder produces heat to generate power in about the same way as a burner reactor.

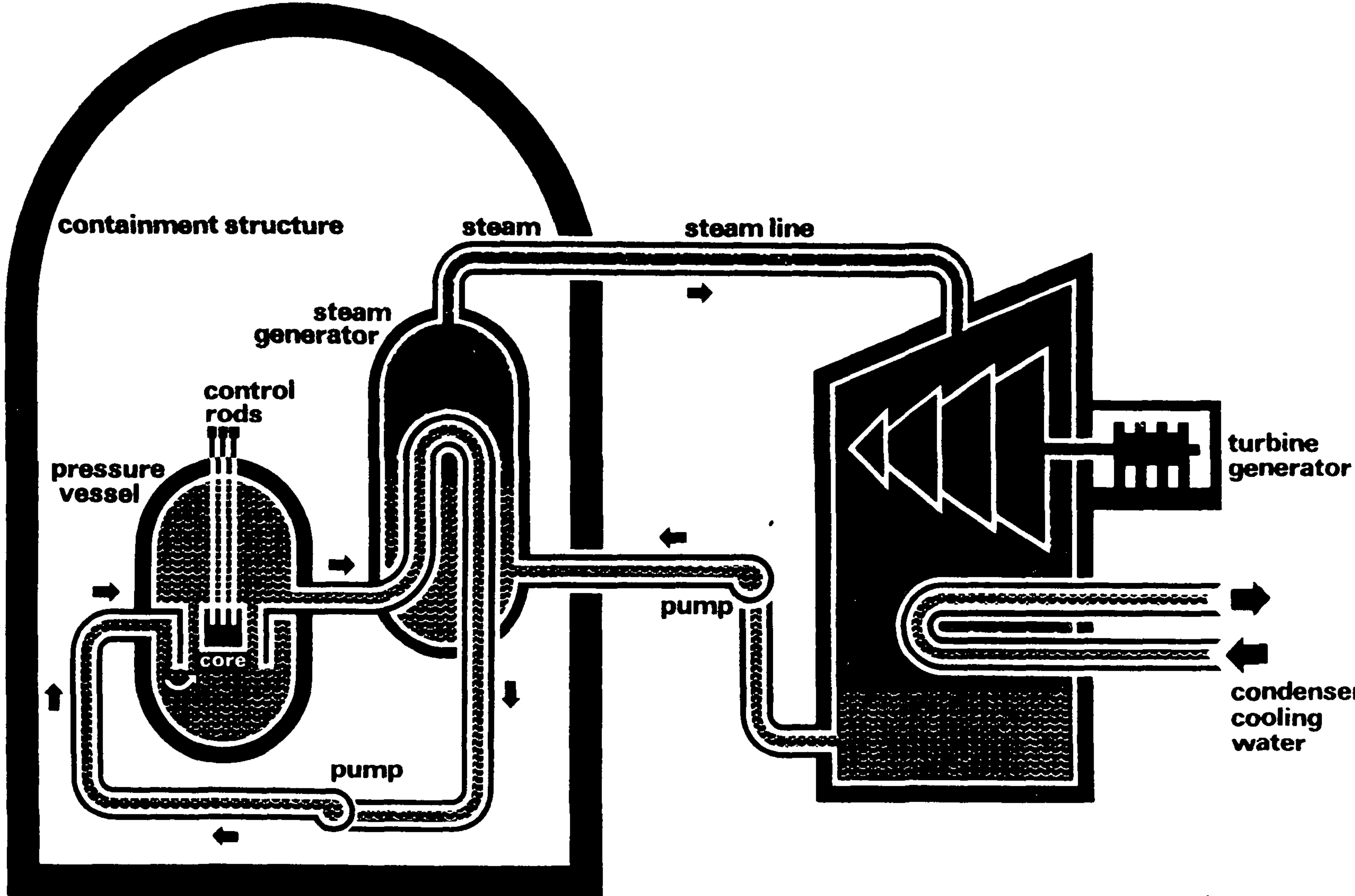
Burner Reactors: Burner reactors are currently commercially available in the U. S. and abroad. In the U. S., light water (ordinary H_2O) cooled reactors (LWR) of either the boiling water (BWR) type (figure XI-E-6) or pressurized water (PWR) type (figure XI-E-7) are most common in commercial use. In 1974, about six percent of the total power generation was derived from light water reactors. By 1976, this percentage had increased to about ten percent.



BOILING WATER REACTOR (BWR)

Figure XI-E-6 Boiling Water Reactor

Source: Atomic Industrial Forum, Incorporated



PRESSURIZED WATER REACTOR (PWR)

Figure XI-E-7 Pressurized Water Reactor

Source: Atomic Industrial Forum, Incorporated

Other less developed burner types include gas cooled reactors, organic fluid cooled reactors, and liquid metal cooled reactors.

In general, the above types of burner reactors require "enriched" uranium for operation. The enrichment process increases the fraction of fissionable U-235 in a uranium fuel from the normal 0.7 percent as found in nature to about three percent. The enrichment process involves a complex selective filtration operation based on the small but significant mass difference between U-235 and U-238 atoms. The process involves chemical conversion of the solid uranium ore into a gas.

In Canada, the heavy water (deuterium oxide, D_2O) cooled and moderated reactor is commercially available. This type of reactor does not require enriched uranium but because of the superior moderating qualities of D_2O, may use natural uranium. This type of plant does require extensive facilities for separating D_2O from ordinary water. The concentration is only 0.016 percent.

Technology Status: The technology status of PWR and BWR power plants is relatively mature in the U. S. However, plant costs have risen sharply in recent years due to inflation, construction delays, fuel ore cost increases, and stringent environmental and safety design requirements. About 60 units are presently in commercial operation in the U. S. comprising about 35 GW.

Four major commercial suppliers of reactor hardware are available. About 155 additional units are on order or will begin commercial operation by 1990. The ERDA is funding LWR technology with emphasis on fuel cycle development. The primary improvements under development are in the areas of nuclear waste management and nuclear materials security and safeguards. Energy conversion efficiency (heat-to-electricity) is about 32 percent (maximum), being limited by maximum fuel operating temperatures.

The key problems associated with LWR reactor utilization are uranium supply; plant siting difficulties, cooling water, waste management, proximity to population; and high costs to assure reliability and safety. Estimates vary, but it is generally acknowledged that proven uranium reserves are on the order of 10^6 tons, which at the projected rate of consumption in 1985, would last only about 20 years.

Projections: It is projected that LWR plants will continue increase in utilization through the 1980's subject to environmental constraints and/or potential legislation that could limit widespread use. Nuclear waste management and plant siting are a key limiting factors.

Environmental Considerations: The normal operation of a nuclear reactor produces radioactive liquid and gaseous and solid waste materials, in addition to being a source of thermal pollution. Open pit uranium mining operations also pose potential environmental concerns related to land use, water pollution, and air pollution by mining machinery.

Underground mining of uranium raises the controversial question of exposure of miners to radioactivity, primarily radon gases released from uranium ores. Because of their lower operating temperatures, light water reactor powerplants are less efficient in converting heat to electricity than are modern fossil fuel plants. As a result, more cooling water per megawatt output is required in an LWR than in a modern fossil fuel plant. This characteristic is undesirable in an area that already lacks water for other purposes.

Probably the most significant environmental issue associated with LWR powerplants is radioactive waste management. Waste management must be exercised in practically all stages of fuel handling from mining through final reprocessing and disposal/storage. The handling problem becomes more significant once the fuel has been used or irradiated to produce power. The radioactive wastes include reactor core structural materials, coolants, and processed fuel elements.

The primary objective of handling these wastes is to minimize their volume and thus reduce their required storage space. The liquid wastes are concentrated as much as possible and then chemically converted into a dry, granular solid material. The material is then put into heavy steel containers and transported to federally controlled burial caverns.

Certain abandoned salt mines provide the most stable and geologically sound storage space.

Research is being conducted to develop new ways of disposing of the highly radioactive wastes. Methods are being explored to concentrate the wastes to even smaller volumes.

Economic Considerations: The costs of light water reactors (boiling water and pressurized water types) have risen sharply in the last 5 to 10 years due to inflation and the high cost of implementing safety and environmental protection features. The construction time for a typical 1000 MW nuclear power plant is 8 to 10 years.

The plant capital costs constitute the majority of the nuclear electric generation costs and dictate that the plants be used as base load units. On the other hand, fuel costs are, percentagewise, much lower than in fossil fuel plants. The fuel portion of a fossil plant generation cost ranges from 30 to 50 percent, whereas in a nuclear plant the fuel cost is 10 to 20 percent of the cost to produce electricity. It is expected, however, that as low cost uranium becomes more scarce, the fuel costs will escalate, thus driving up the generation cost.

Typical costs for LWR nuclear power range from $600 to $1100 per kilowatt (installed). The cost range reflects variations primarily associated with site location (local labor cost, land, land preparation, cooling method, etc.) and the cost of capital at the time. Power generation costs range from 17 to 35 mills/kwh and consists of 13 to 27 mills/kwh for capital, 3 to 6 mills/kwh for fuel, and 0.7 to 1.7 mills/kwh for operations

and maintenance. All costs are expressed in 1976 dollars.

e. HYDROELECTRIC POWER: Water used for power development purposes, such as in streams, rivers, and lakes, derives its energy from the radiant energy of the sun through the hydrologic cycle. This cycle is accomplished as water from ground and water surfaces is evaporated by solar radiation into the atmosphere, the vapor is then cooled and condensed and falls back to earth as precipitation. The precipitation falling on highlands frequently accumulates into streams and lakes in sufficient quantity and with sufficient potential energy remaining (as dictated by the terrain) to be utilized for power generation.

Water power has been a source of energy to perform a significant portion of man's work for many centuries. Early applications consisted primarily in the grinding of grain, but this century's lifestyle and its high demand for electrical power has dictated a far greater utilization of this resource for the purpose of hydroelectric power generation. As a result, the nation has been extensively surveyed for practical sites to determine the combination of water flow rates and heads which are essential for successful utilization.

Utilization Forecasts: Table XI-E-1 lists the developed and undeveloped (but physically feasible) hydroelectric site potentials by geographic division in the United States. This data, taken from the 1975 Statistical Abstract of the United States, shows that approximately one-third of the total potential is currently utilized. The same reference also shows that hydroelectric power furnished as much as 29 percent of the total electric energy production in 1950 and has decreased almost linearly to about 15 per cent in 1973. Although an increasing amount of electric power has been supplied by hydroelectric plants during this period, other conventional sources have made up most of the increasing demand. This ilustrates the major limitations of hydroelectric power as we look for major contributors to increasing energy needs. Not only is water power restricted by number of feasible sites, but especially within the past decade, restricted by an increasing concern for the environment and possible environmental effects. This, and the fact that hydroelectric plants take nearly a decade to place on-line, supports the projection that water power will continue to suppliment our electric energy requirements with only a slowly increasing total output for the remainder of the century. However, the relative contribution compared to other alternate energy sources will steadily decrease as total demand skyrockets.

Technology Development: As a result of tapping hydroelectric power for many years, the state-of-the-art is well advanced. Efficiencies for extracting the potential energy and conversion to mechanical and then electrical energy are very high. Breakthroughs, therefore, cannot be expected to provide significant contributions to the total energy picture.

Environmental Considerations: Changes to the environment due to creating large reservoirs, lakes and altering shorelines, both permanently and by the rising and lowering of backwater levels, is a major

WATER POWER IN THE U.S. - DEVELOPED AND ESTABLISHED UNDEVELOPED
BY GEOGRAPHIC DIVISION - MEGAWATTS

AS OF 1973

DIVISION	DEVELOPED	UNDEVELOPED*	TOTAL
EAST	11,203	16,694	27,897
CENTRAL	11,282	12,231	23,513
MOUNTAIN	6,665	21,829	28,494
PACIFIC	25,824	68,448	94,272
TOTAL	54,974	119,202	174,176

*ALL PHYSICALLY FEASIBLE SITES, MEAN-FLOW POTENTIAL. DOES NOT INCLUDE PUMPED STORAGE CONSIDERATIONS.

Table XI-E-1

concern when considering the suitability of dam sites. The considerations of covering homesites, historical locations, natural attractions, etc., has become much stronger. The impact of such changes weighed against the significant advantages, such as those listed in Table XI-E-2, will nevertheless dictate that maximum developed utilization of hydroelectric power in the United States will fall far short of the physical potential.

Cost Projections: Due to the variety of sizes and varying potentials of existing hydroelectric plants, the cost averaging techniques used in Hydro Power Engineering by James J. Doland, University of Illinois, have been used and projected to 1975 dollars. Figures XI-E-8 and XI-E-9 show the range of capital costs and production of Federal hydroelectric facilities as a function of average water head and plant size. Incorporating the assumptions listed on Table XI-E-3, the average cost of electrical power from new hydroelectric plants coming on-line in 1975, is about 10 mills/kwh. This compares with 14-35 mills/kwh from oil/gas/coal/nuclear electrical power generation the same year. Startup of hydroelectric plants in 1995 are estimated at about 18 mills/kwh using the projections listed.

2. Advanced Systems

a. BREEDER REACTORS: Breeder reactor technology development began in the late 1940's in the United States. The Experimental Breeder Reactor I (EBR-I) was the first nuclear reactor system in the world to produce electric power (1951, Arco, Idaho).* A number of breeder reactor concepts have been pursued, but the liquid metal-cooled, fast breeder reactor is probably the most technically advance. A large number of liquid metal-cooled reactors have been built including the Sodium Reactor Experiment (SRE), the Hallam Nuclear Power Facility (HNPF), the Experimental Breeder Reactor (EBR) and several foreign reactors. The term "fast" used in the description of breeder reactor concepts refers to the neutron energy level and is contrasted against "slow" or thermal neutron energy levels of moderated, burner-type reactors previously described.

Technology Status: The U. S. government (ERDA) is currently sponsoring major efforts in breeder reactor technology, The Liquid Metal-Cooled Fast Breeder Reactor (LMFBR) program is the focus of this activity which is funded at about $650 million annually. A major part of this program is the design, license, and construction operation of the 380 Mw (electric) Clinch River demonstration plant located near Oak Ridge, Tennessee. The demonstration startup is scheduled for early 1984. The operating program will continue for a period of 5 years to demonstrate and document reliability, maintainability, availability and operating economy of a breeder reactor on a utility grid.

World-wide, a total of eight countries are sponsoring breeder reactor development efforts. France has recently completed a two-year operation of the 264 Mw Phenix reactor with a plant capacity factor greater

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* Nuclear Engineering Handbook, Etherington 1958.

ASSOCIATED CONSIDERATIONS OF HYDROELECTRIC UTILIZATION

(1) ELECTRICAL POWER GENERATION

- A. BASE LOADING - OFTEN COUPLED WITH STEAM/ELECTRICAL PLANTS
- B. LOAD FOLLOWING - COMPLIMENTS VARIABLE GENERATING PLANTS SUCH AS SOLAR OR WIND-DRIVEN.

(2) FLOOD CONTROL

(3) IRRIGATION

(4) RECREATION

(5) TRANSPORTATION

(6) PUMPED STORAGE

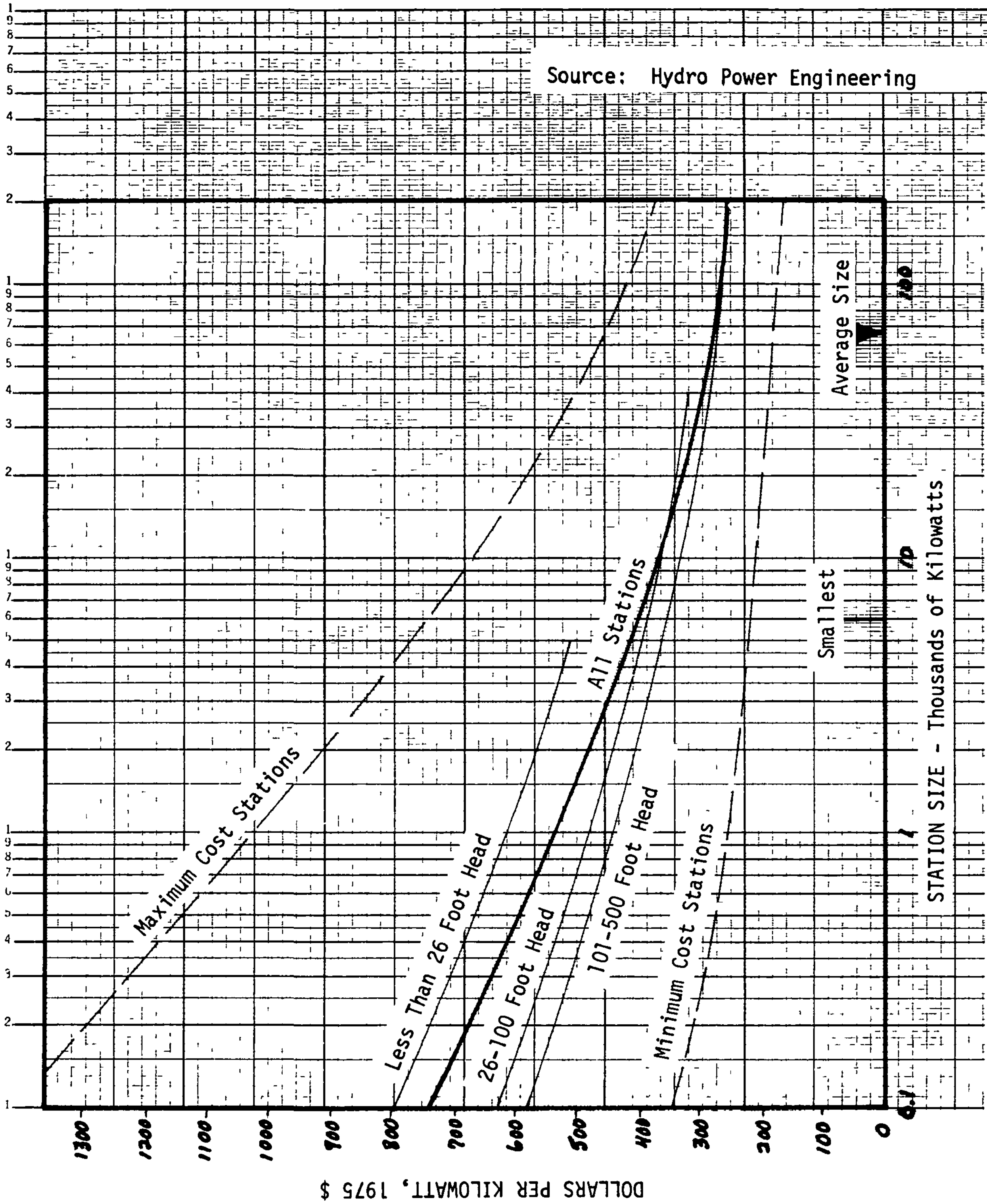
(7) HEAT REJECTION - HEAT PUMP SINKS, COOLING "PONDS"

(8) HEAT GAINS - HEAT PUMP SOURCES

(9) FIRE CONTROL

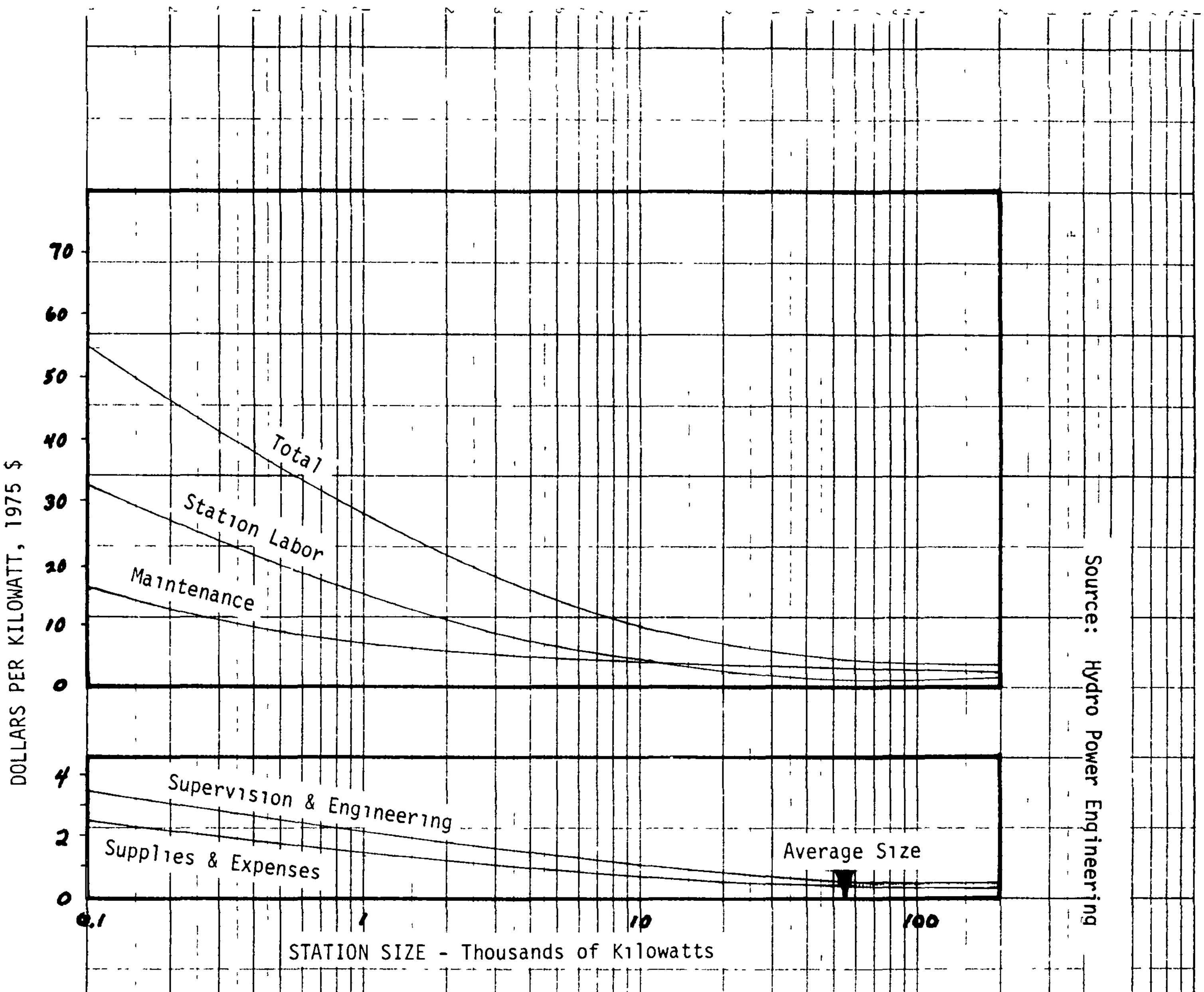
(10) RESERVOIR FOR INDUSTRIAL AND DOMESTIC USES

Table XI-E-2



RANGE OF CAPITAL COSTS OF FEDERAL HYDROELECTRIC FACILITIES PER KILOWATT OF INSTALLED CAPACITY

Figure XI-E-8



PRODUCTION EXPENSES OF FEDERAL HYDROELECTRIC FACILITIES

Figure XI-E-9

ASSUMPTIONS

COST OF CONSTRUCTION CAPITAL 8%

RATE OF RETURN 15%

CAPITAL COST INFLATION 5%

O & M INFLATION 6%

CAPITAL COST $275/KW (1975 $)

O & M COST $4/KW/YR (1975 $)

CONSTRUCTION TIME 9 YEARS (UNIFORM)

PLANT LIFE 40 YEARS

PLANT SIZE 56,000 KW

PLANT FACTOR 62.3%

POWER INFLATION RATE 2%

RESULTS

1975	START UP	10.05 MILLS/KWH.
1995	START UP	18.35 MILLS/KWH.

Table XI-E-3

than conventional power plants.

Environmental Considerations: As in the case of burner-type reactors, breeder reactors produce radioactive liquid and gaseous and solid waste materials. In addition, they are a source of thermal pollution. The primary objective in the handling of radioactive wastes is to minimize their volume to reduce storage space. The material is generally put into heavy steel containers and transported to federally controlled burial caverns. Certain abandoned salt mines provide the most stable and geologically sound storage space.

Economic Considerations: The capital and operating costs of breeder reactors are somewhat uncertain at this point, but the minimum estimate is about one-third more than a light water reactor (LWR). This higher cost is associated with liquid metal (sodium) systems primarily. Fuel costs for LMFBR are estimated to be substantially lower than LWR because essentially no new uranium purchase is required.

Projection: If the LMFBR program (and its associated plutonium fuel cycle) is continued in the U. S., the LMFBR will reach commercial status by 1988-1990. Under these conditions, up to about 10 percent of the U. S. electrical production could be provided by the LMFBR. The widespread utilization of LMFBR may be limited by high cost (capital) and environmental/safety constraints.

b. NUCLEAR FUSION: Electrical power may be produced from the heat generated by the controlled nuclear fusion reaction. Unlike a fission reaction, which produces energy by splitting heavy atoms of uranium isotopes, fusion produces energy by combining or fusing the lightest of all atoms--the isotopes of hydrogen. Nuclei of all atoms have a positive charge and, therefore, repel each other as they are brought close together, just as two magnets of the same pole repel each other as they converge. Fusing two atoms of hydrogen together requires tremendous heat and pressure to overcome the repelling forces. The source of our sun's energy is an example of a fusion reaction; hydrogen atoms are continually fused together by the sun's tremendous heat and gravitional forces.

Fusing the two hydrogen isotopes, deuterium and tritium, is the most efficient method for a man-made fusion reaction. Deuterium is very plentiful in nature; all water contains a small percentage of the isotope. Tritium does not occur in nature and must be synthetically produced from lithium, which is abundant in nature. Lithium atoms must be subjected to a neutron bombardment which splits its atoms into helium and tritium. The splitting action is similar to a uranium atom's being split in a fission reaction.

Tritium atoms are radioactive and pose the primary environmental concern for a fusion reaction. The atoms are so small and light that under pressure they can diffuse through most materials normally used to fabricate reactor walls. Should radioactive tritium escape into the atmosphere, it could conceivably contaminate air and drinking water. If

the contaminant were ingested by man, it could cause serious health damage. Advanced technology in the fusion process should be able to contain and control any leakage of the radioactive gas. New ceramic materials that will contain the gas or new techniques to convert the gas into a safe form will probably be developed.

Two basic methods are being pursued to develop the required heat and pressures for a fusion reactor: magnetic containment and laser beams.

A magnetic containment fusion reactor uses a magnetic field to raise the temperatures, the fuel materials cannot come in contact with reactor walls; otherwise, the hydrogen atoms would rapidly cool or the reactor walls might melt. The fuel materials must therefore be suspended in free space with no mechanical support. In the reactor, powerful magnetic fields provide the required suspension. All nuclei of atoms have positive charges and can be repelled by positively charged magnetic fields, just as magnets of the same pole repel each other.

The reactor is a tube-shaped vessel of various configurations with powerful donut-shaped magnets ringing its circumference. The positive-charged magnets cause the gaseous fuel inside the reactor tube to be repelled on a 360-degree circumference, thus suspending it in free space.

Several methods have been proposed to raise the fuel temperature to the required level. One promising method requires a magnetic-pumping action, using a series of magnets surrounding the inlet port to the reactor. As the gaseous fuel is introduced, the magnets suddenly increase their strength in a progressive manner, causing the gas to compress and heat forming a plasma. The reactor's pumping action would be required only to begin the fusion reaction; once started, the reaction would be self-sustaining.

The fusion reaction causes hydrogen isotopes to fuse together, emitting neutrons from their nuclei and releasing heat. The heat of fusion is carried away by a coolant liquid which flows around the outside of the reactor vessel, but inside the magnetic rings. The hot liquid is pumped through a heat exchanger where its heat is transferred to a secondary loop containing flowing water. The exchanged heat boils this water, and the resulting steam is directed through an electric turbine generator. After spent steam has passed through the generator, it must be condensed back to water. The cooling water required could be a source of thermal pollution.

The reactor's coolant is liquid lithium; thus, in addition to conveying of heat, it can also provide a source of tritium. As previously mentioned, tritium can be produced synthetically by neutron bombardment of lithium. While liquid lithium circulates around the reactor vessel, it would be continually bombarded by neutrons emitted from the fusion reaction. Neutrons have no electrical charge and therefore are not restricted or contained by the magnets. A portion of the lithium is converted

into tritium, which can be distilled from the coolant and used for fuel in the reactor.

A laser fusion reactor develops the required heat and pressure for a fusion reaction to occur from a laser--a device that transmits a source of high energy by a pure and precisely focused beam of light. The reactor is a spherical-shaped hollow vessel having numerous equispaced portholes situated in its walls to allow passage of laser beams. Fuel for the reactor is composed of small pellets of deuterium and tritium, mixed together and frozen at a temperature of near absolute zero. The normally gaseous hydrogen fuel material must be solidified so it can be injected into the reactor's center.

The solid fuel pellets are injected into the reactor sphere at a rate of two or three per second. At the precise instant the pellet reaches the sphere's center point, laser beams instantly and simultaneously hit the pellet to explode with a tremendous force. Since every action creates an equal and opposite reaction, the explosion causes a concurrent implosion. The imploding force, in conjunction with the heat conveyed by the laser, cause the nuclei of the hydrogen isotope atoms to fuse together, releasing heat and emitting neutrons.

The heat of fusion is carried away by a blanket of liquid lithium flowing around the outside of the reactor's sphere. Similar to a magnetic containment fusion reactor, the liquid lithium conveys heat for producing steam for electricity production and is also the source of tritium resulting from neutron bombardment.

Technology Status: Several laboratory scale magnetic confinement fission reactors have been operated intermittently. No continously operating reactor has been built to date. Minimum plasma densities were achieved in 1953. Minimum temperatures were attained in 1962 and adequate confinement was demonstrated in 1962. Simultaneous achievement of these minimum parameters is yet to be accomplished.

The ERDA magnetic fusion power program has been directed toward developing an understanding of reactor-level hydrogen plasmas and the associated technologies. According to ERDA-76-1 (June, 1976), this understanding has been developed and the next step is the design, construction, and operation of a Tokomak Fusion Test Reactor (TFTR), which will be the first energy-producing fusion experiment. This facility is scheduled for completion in the 1980-1981 time period. The mid-term (2000) goal is to produce electrical energy in quantities in two experimental power reactors and operate a commercial scale power reactor.

The laser fusion program sponsored by ERDA is less developed than the magnetic fusion approach. Research is in the program to demonstrate a significant fusion burn and "scientific breakeven", which means that the energy yield is just equal to the energy input to initiate the reaction. Both laser and electron beams are being investigated.

Environmental Consideration: It appears to be far too early to ascertain the full range of environmental implications of fusion reactors. Similarities with fission reactors will exist, particularly with respect to radioactive wastes and waste heat rejection.

Economic Considerations: Potential capital and operating costs of fusion power plant concepts have been estimated several sources*; however, the estimates are somewhat speculative because the technology for satisfactory reactor design is still under development.

Projections: Concentrated fusion power research has been in progress only six to eight years. Prior to that funding levels were too low to make substantial progress, owing to the high cost of the equipment needed. With the current program funding levels, substantial program is being made but it is not expected that fusion power will reach commercial status until after 2000.

c. TERRESTRIAL SOLAR POWER

1. Photovoltaics: When light energy falls on some crystalline semiconductors, it may excite the electrons to jump from the valence band to the conduction band of the substance. A result of this electron transfer is that the electrical resistance of the substance is changed proportionally, making it a good detector of the quantity of incident light. Used in this fashion, the semi-conductor is called a photocell. If the excited electrons are allowed to return to their original band by passing through a useful load, a small quantity of electrical power is generated and the semi-conductor is called a solar cell.

The direct conversion of sunlight to electricity by use of solar cells is a very enticing alternative because of its pollution-free potential. However, the output of each cell is limited by the low energy of incident sunlight on its limited crystalline size and its low conversion efficiencies (8 to 15 per cent). The result is that for quantity electrical production, great numbers of solar cells must be coupled. The large solar panel arrays used in the Space Program serve as the most conspicuous application of this. It is apparent that solar arrays can be located very near the electrical energy user, thereby minimizing distribution costs. However, the necessity of an electrical power storage system to provide for nighttime requirements or low sunlight periods becomes a greater factor with the smaller systems. This and the overall economy of scale suggest a central power station arrangement such as pictured in figure XI-E-10. In this representation,

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*1.) Robert G. Mills, Princeton University, IECEC 1974, paper no. 749076.

2.) R. W. Conn and Gerald L. Kulcinski, University of Wisconsin, Science Volume 193.

3.) Lawrence Radiation Laboratory, J.D. Lee, R.W. Werner, et. al., IECEC 1970 #709007.

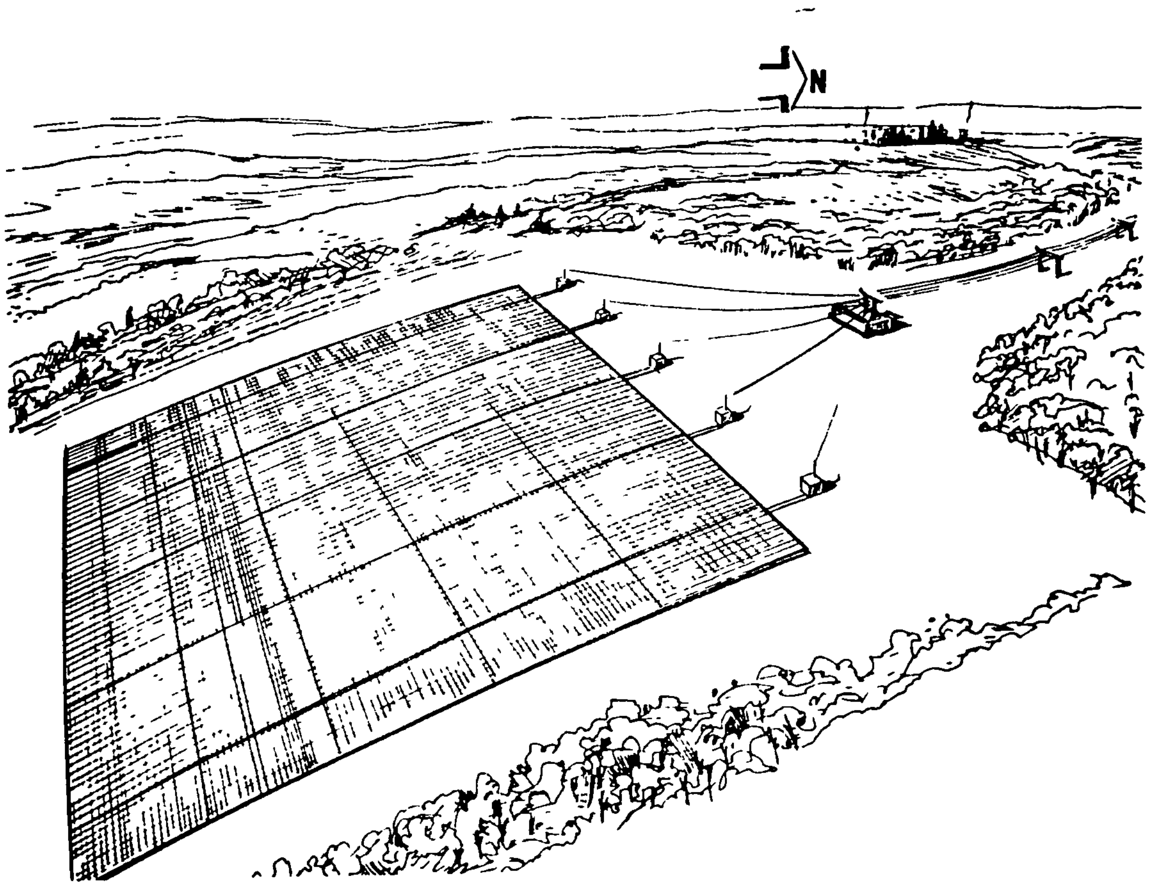


Figure XI-E-10 - One Square Mile Terrestrial Solar Power Plant

the solar cells are simply oriented on the southern slope of a hill. Cells within groups would be arranged in series to elevate the voltage to an economical distribution level and the groups paralleled in sufficient quantities to allow a reasonable load capability. Obviously, some form of energy storage is necessary for continous electrical production, but this requirement can be lessened if the solar system is coupled in a grid with more versatile generating stations.

Utilization Forecasts: Although the photovoltaic phenomena was first reported in 1839, it wasn't until 1954 that practical conversion efficiencies (approaching 10 per cent) became available. The production of solar cells began in the United States in 1957 and until recently has been reduced from about $500/watt in 1958 to less than a tenth of that currently, the cost is still far from competitive for quantity terrestrial electrical energy production. Because the photovoltaic energy conversion technology is essentially in the research and development stage, it is difficult to predict a meaningful cost and utilization forecast for terrestrial use. Referencing Volume 2 of "A National Plan for Energy Research, Development and Demonstrations: Creating Energy Choices for the Future-1976" (ERDA 76-1), it is stated that the long-term goal of the program is "to make possible a solar photovoltaic capability in the private sector that may approach 50 GW_e peak by 2000 with a market price as low as $100 to $300 per peak kilowatt."

Technology Development: There is significant emphasis in Solar Photovoltaic Conversion (SPC) as indicated in the FY77 federal budget. Of the $290.4 million earmarked for solar energy development (which represents 18 per cent of the non-nuclear program's energy budget), $64 million is devoted to solar cell R&D according to the Congressional Record. Figure XI-E-11 shows the milestone chart in which ERDA projects technology development. Quoting from ERDA 76-1:

> "The central element of the strategy in this program is to lower the cost of collector arrays by a factor of 50 to 100 from present levels. This will be done through R&D on production of low-cost photovoltaic materials, large-area crystal growth, high volume sheet production, materials and techniques for array encapsulation, improved cell and array designs, and high-volume, cost-effective, automated assembly techniques.
>
> The experimental testing and demonstration of SPC systems will be based on applications that promise early cost effectiveness, wide user acceptance and significant market development by the private sector.
>
> Emphasis is initially on the use of single-crystal silicon because of the abundance of silicon and the availability of proven techniques for production of large single crystals. However, alternative techniques and materials such as gallium arsenide and cadmium sulfide, are also being developed.

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

PHOTOVOLTAIC ENERGY

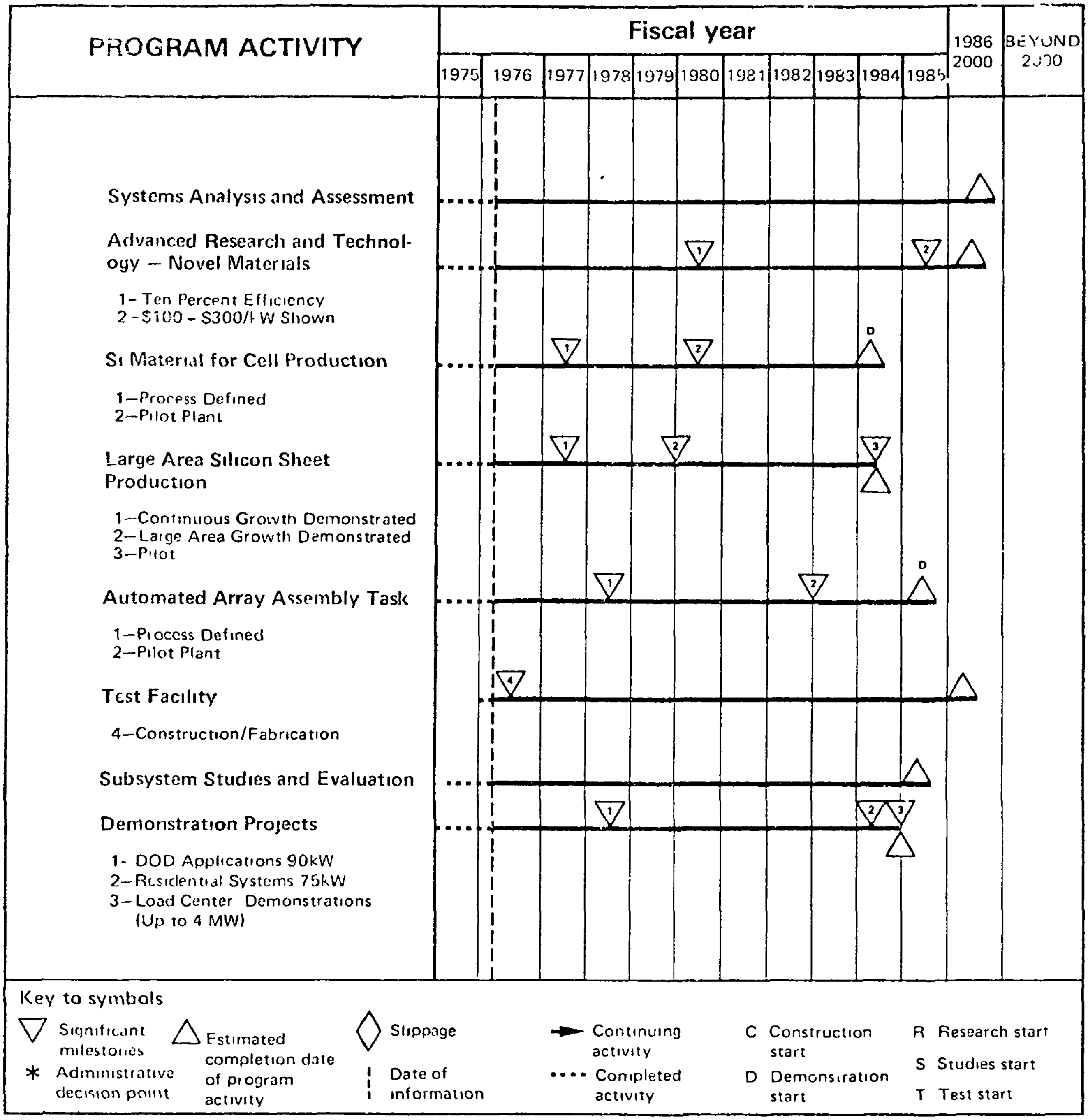


Figure XI-E-11

Assuming the success of the above stragety the following could occur: by FY83 pilot plants capable of producing in excess of 5 million m^2/year of silicon sheet at a value-added cost of less than \$18/m^2; the establishment, by FY84, of plants capable of producing about 2,000 metric tons, of silicon materials at a market price of less than \$10/kgm; and the establishment, by FY85, of plants capable of producing in excess of 500MW/year (peak) of encapsulated solar array modules at a market price of less than \$500 per kW (peak)."

Environmental Considerations: The most attractive advantage of the solar cell is its ability to convert an abundant and replenishable energy source (sunshine) into a highly usable energy form essentially pollution-free. During photovoltaic generation, no wastes are produced, no unusual safety problems arise, no radioactivity is released, and for most uses, no thermal problems are encountered other than those normally associated with darkened materials exposed to long periods of sunshine. For many small-scale applications, space used for solar collection may be used for other purposes as well, such as roofs and walls. The cental power station concept requires large areas, but their utilization could be limited to otherwise uneconomically problems are the problems of safety associated with possible means of energy storage such as batteries and fuel cells.

Cost Projections: Several cost projection objectives of the current U. S. photovoltaic conversion programs have been mentioned earlier in this section. Some of the major milestones used in developing a comparative cost analysis are:

o Reduction of solar array costs to \$500 per peak kilowatt by 1985 with an annual production of 500 mW per year.

o Combined costs of collectors and cells using concentration to be \$250 per peak kilowatt.

o Demonstration of thin-film array technology leading to array costs of \$100-\$300 per peak kilowatt.

o Terrestrial environment lifetime of at least 20 years.

Studies performed by the Jet Propulsion Laboratory for the NASA Office of Energy Problems show that using "the \$0.50/W_p goal, the photovoltaic plant is 25 per cent to 60 per cent more expensive than the solar thermal plants as solar load factor goes from 0.3 to 0.70. Lower *goals may be necessary before the photovoltaic plant is competitive with* other ground solar approaches for central electric power."

Comparative costs with other systems are covered more extensively in a concluding section to Alternate Systems.

2. Thermal Conversion: The central receiver arrangement or "power-tower" is the primary terrestrial solar concept examined for the large-scale conversion of solar energy into thermal and then to electrical energy. This concept is illustrated in figure XI-E-12 and consists of several major subsystems. A field of tracking mirrors (heliostats) reflect the collected solar energy onto a central receiver. This concentrated energy is transferred to a steam turbine-generator facility for electrical power generation. The transfer medium is returned to the receiver after cooling by use of a condensor-cooling-tower loop. A storage system may be integrated into the basic system to allow uninterrupted dispersion of electrical energy during periods when sunshine is unavailable. However, when the solar system is used in combination with another electrical power generation system such as hydroelectric, the need for a storage system may be minimized.

Utilization Forecasts: The production of large quantities of electrical energy from direct solar energy is in an infant stage of development. Only one sizeable facility has been built (at Odeillo, France), and this has served as a worldwide solar laboratory for many years. Another project, scheduled for operation in 1978, is a 5 MW test facility under construction at Albuquerque, New Mexico. Until the development of the solar central receiver technology has substantial field testing for the variety of equipment options it offers, utilization forecasts are highly speculative.

Technology Development: The central receiver concept requires no major breakthroughs; however, the program is dependent on new technology in order to become cost competitive in the production of electrical energy. Initially, major work on the concept was funded by NSF (National Science Foundation) grants, but several years ago, ERDA (Energy Research and Development Administration) assumed responsibility for the project and designated Sandia Laboratories of Livermore, California, as the technical manager. Under this guidance, three contract teams are working in parallel to develop preliminary designs of a 10 MW plant. A fourth major contractor is concentrating entirely on the heliostat subsystem. Research and development initially is centered on providing low-cost components. The three major subsystems that require substantial development are the collectors, the receiver and the storage facility.

Figure XI-E-13 shows the 10 MW Pilot Plant Project Milestones and the initial results of the four study contracts available in mid-1977. Site selection for the 10 MW pilot occurred as scheduled in January 1977 and Barstow, California was chosen. Site preparation and construction on the 10 MW plant are expected to begin in mid-1978 and checkout two years later. Obviously, reports on the details of technological development should become available from the final Phase I report period through the remainder of the five year schedule.

Figure XI-E-14 illustrates the long-range plans for Central Receiver and Test Facility Projects. This orderly technological development will allow accurate utilization forecasts within the decade.

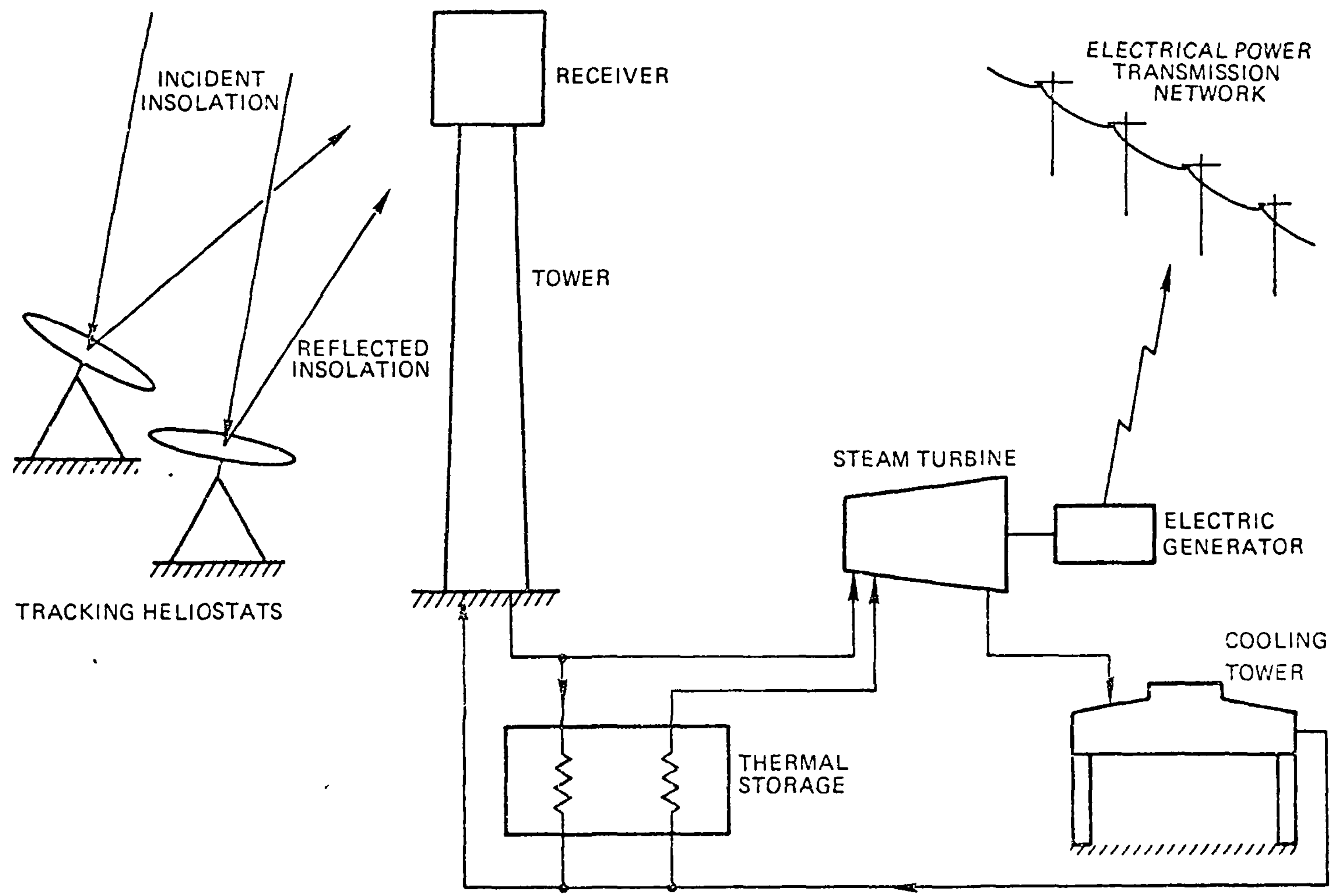


Figure XI-E-12. Central Receiver Solar Thermal Power System

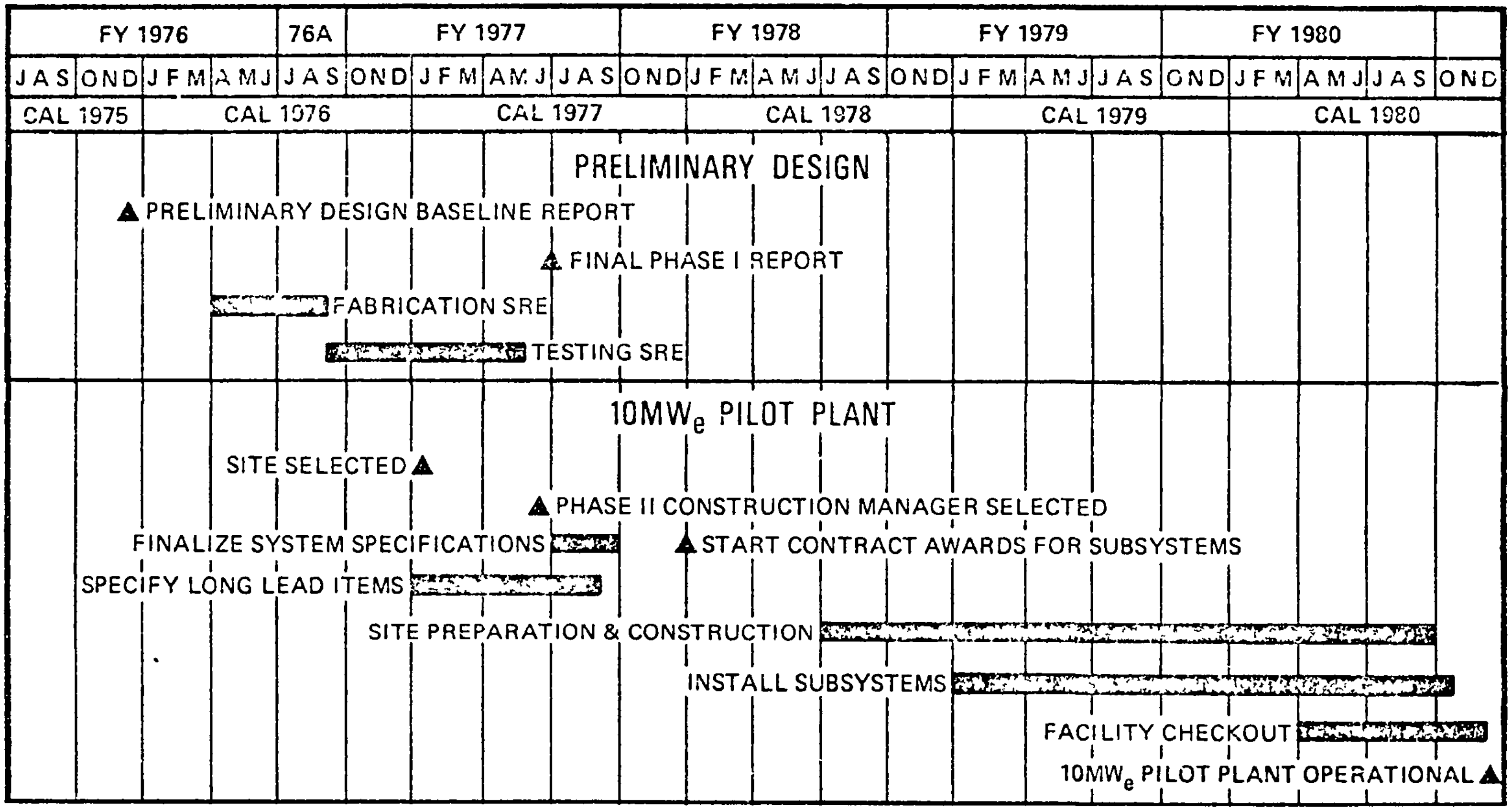


Figure XI-E-13. 10 MW_e Pilot Plant Project 5 Year Milestone Schedule

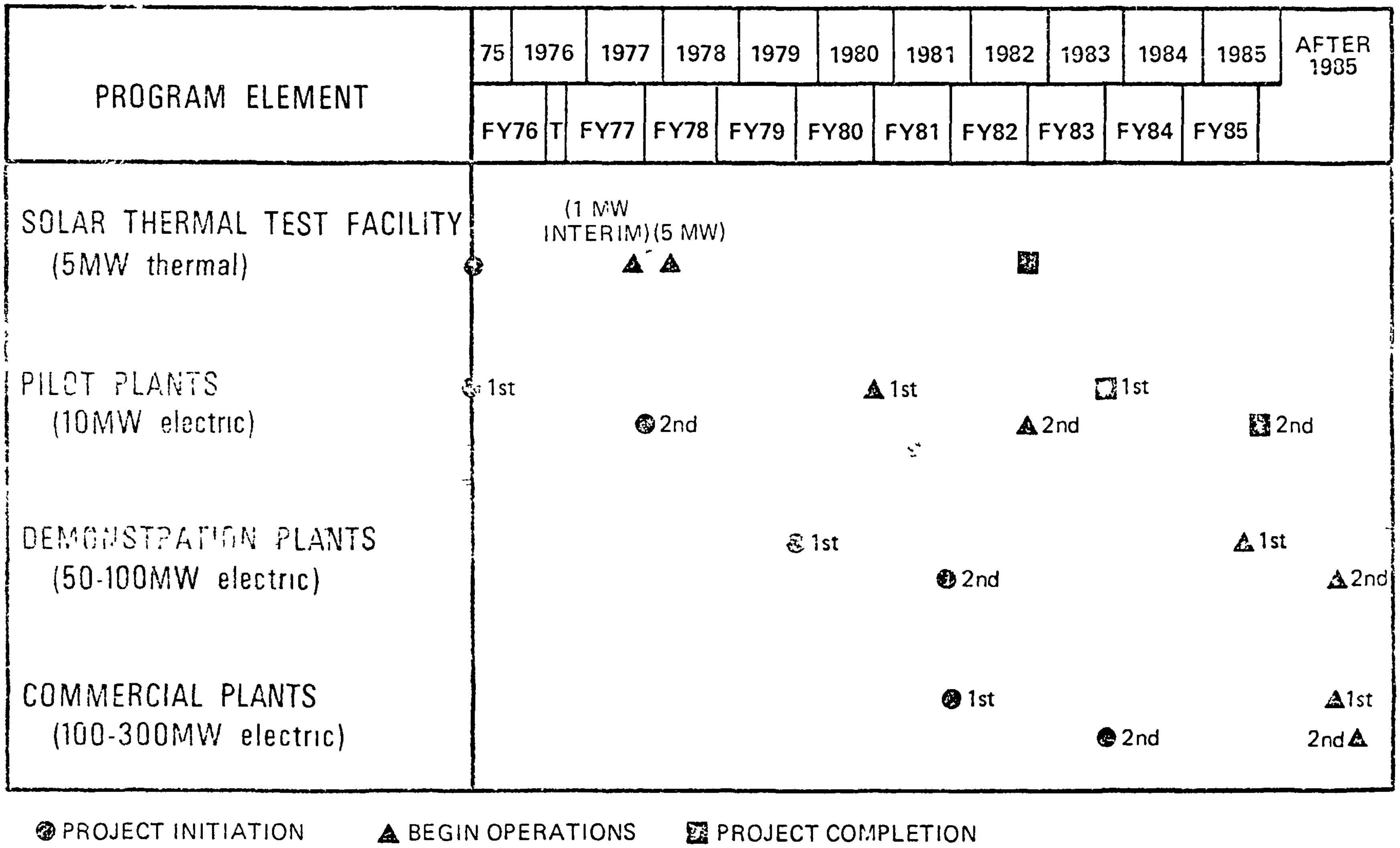


Figure XI-E-14. Central Receiver and Test Facility Projects

Environmental Considerations: The land requirements of the solar central receiver concept are very substantial. The 10 MW pilot plant designs presented in the study contracts all require approximately 100 acres. Since commercial size conventional (fossil-fueled) plants frequently run greater than 1000 MW for economy of scale, it follows that much larger solar central receiver systems would be planned. Obviously, the solar "farms" would have to be located in good sunshine areas at remote (inexpensive land) sites from load centers. These requirements alone may be seriously restrictive. Another question that remains unanswered is what effect on local weather conditions will large fields of reflective surfaces produce? Hopefully, the long range test projects will be able to answer this.

Cost Projections: Figure XI-E-15 shows the results of a comparative cost analysis on similar central receiver concepts by JSC and JPL. The major considerations for each analysis are presented and it can be seen that projected energy costs for plant startup in the year 2000 range between 123 and 193 mills/KWH. Obviously, cost projections for these systems are extremely "soft." The proposed system development will allow much more accurate estimates in a few years.

d. GEOTHERMAL ENERGY: The distribution of thermal energy and temperatures beneath the earth's surface give rise to geothermal resources. The more widely known and accepted forms of geothermal energy, geysers, boiling pools of mud, fumaroles, and hot springs, are exploited to some extent. However, because the need for more energy has pushed exploration, which has exposed a rather extension resource, a great untapped energy potential exists. The evidence reveals a world-wide distribution of geothermal energy reservoirs beneath the earth's surface.

There are three types of resources for geothermal energy; steam, hot water, and hot rock. The steam resource can be subdivided into two types: wet steam or dry steam which is the most desirable, in that with little pretreatment to remove corrosive materials, it can be directly piped to a turbine to produce electricity. Requirements for plant equipment are greatly reduced because there is no need for boilers, furnaces and storage tanks for fuel. A simple schematic of dry steam power plant is shown in figure XI-E-16.

The problems associated with dry steam are mainly due to plant location. Usually dry steam fields are located in isolated, highly structural geological regions thereby making plant construction extremely difficult both from a material transportation standpoint, and from an installation viewpoint. Plants must be close to the steam source to prevent large losses in the piping and to reduce costs by requiring less piping.

As of today explorations into geothermal resources have shown dry steam fields to be a rare phenomenon and have shown wet steam fields to be much more plentiful. Wet steam fields outnumber dry steam fields by at least 20:1 and the prospects for the future are for this ratio to increase considerably. However, continued development of existing fields is expected.

TERRESTRIAL SOLAR POWER - THERMAL

ITEM	JSC	JPL
1. CONCEPT	CENTRAL RECEIVER POWER TOWER - HELIO STATS; SUN TRACKING	-SAME-
2. POWER CONVERSION	STEAM TURBINE - GENERATOR $\eta_c = 40\%$	- SAME - $\eta_c = 19.2\%$
3. CAPACITY, UNIT	5000 MWe (EQUIV. TO ONE 5 GW RECTENNA)	100-150 MWe
4. ENERGY STORAGE METHOD - HOURS STORAGE FOR 0.7 P.F.	HYDROGEN-FUEL CELL/ELECT. CELL ≥ 60	THERMAL-CALORIA-ROCK 12
5. SOLAR INPUT/FIELD AREA	960 KW-H(t)/M^2_1- YR.	815 TO 864 KWH(t)/M^2-YR
(a) AVG. MIRROR DENSITY	(0.5) 1928 KW H(t)/M^2_m - YR.	(0.3) 2716 TO 2880 KWH(t)/M^2_1-YR.
(b) AVG. MIRROR/COLLECTOR EFF. - 73%	2641 KWH(t)/M^2_m - YR.	———
(c) INSOLATION	2641 KWH(t)/M^2_m - YR.	3150 KWH(t)/M^2 - YR.
6. TYPICAL INSOLATION VALUES - DIRECT - 32° LATITUDE	3227 KWH(t)/M^2 - YEAR	
7. LAND USE	448 KWH(e)/M^2_ℓ - YR.	214 KWH/M^2_ℓ - YR.
- EFF. CORRECTION - JSC	215 " "	214 " "
- INSOLATION CORRECTION	256 " "	214 " "
- STORAGE EFF. CORRECTION (0.8 JPL VS. 0.56 JSC)	365 " "	214 " "
- AVG. MIRROR DENSITY CORRECTION	730 $KWH_{(e)}/M^2_m$ - YR	713

Figure XI-E-15

(continuation)

TERRESTRIAL SOLAR POWER - THERMAL

ITEM	JSC	JPL
8. CAPITAL COST, 1975$		
- WITH STORAGE	$4258/KW$_e$ (60 HOURS)	$2450/KW$_e$ (12 HOURS)
- NO STORAGE (ALSO, NO LAND, CONTINGENCY, INTEREST, NOR INDIRECT COSTS)	$870/KW$_e$	$1415/KW$_e$
9. ENERGY COSTS, MILLS/KWH		
- TOTAL (1975 $)	120.0	97.0 (INFLATED "OTHER" AND O&M COSTS)
- NORMALIZED JPL TO 1975$	120.0	76.0
---CAPITAL RECOVERY	(117.0)	(45.0)
---O&M	(3.0)	(7.0)
---"OTHER" (INSURANCE, TAXES, PROFIT, ETC.)	(INCL. IN CAP. REC.)	(24.0)
---YEAR 2000 STARTUP (6% SOLAR POWER INFLATION) (4% GENERAL INFLATION)	193.0	123.0

Figure XI-E-15 (cont.)

STEAM SYSTEM SCHEMATIC

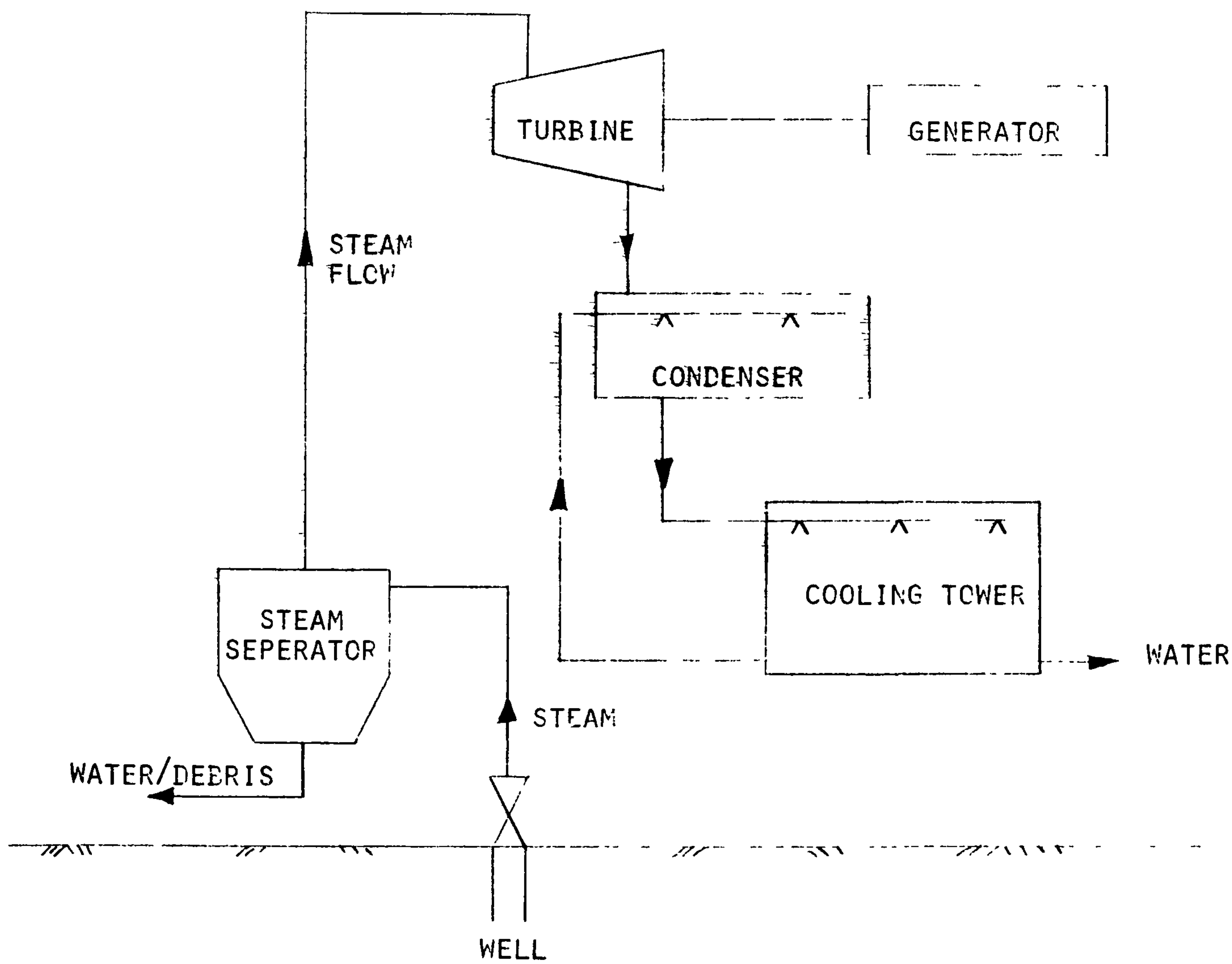


Figure XI-E-16

A wet steam field is an underground reservoir of hot water under pressure. Temperatures of the water are above 100°C or the boiling point at atmospheric pressure, but the pressures at the hot water's depths prevent it from changing into steam. The field is encased in impervious rock. Upon the opening of a fissure or well into the reservoir, the pressure can be released thus allowing the hot water to rise effecting a mixture of steam and water at temperatures ranging from 180 to 370 degrees Celsius. This mixture is composed of 10 to 20 percent steam and hot water.

A wet steam well can produce quantities of steam comparable to a dry steam well, but along with the steam, water is produced which is usually 2 to 3 times as heavy as the steam. Therefore, the utilization of a wet steam field is quite different than that of a dry steam field. The operation of a wet steam plant requires centrifugal separators to separate the water from the steam before it passes on to the steam turbines to produce electricity. Figure XI-E-17 gives a schematic of a wet steam power plant.

Another type of geothermal resource is the hot-water system. Not to be confused with the hot water derived from the wet-steam system, this form is sometimes called a low temperature field. Water temperatures are usually below the boiling point at atmospheric pressure ranging from 50°C to an upper limit of 125°C. At these relatively low temperatures, steam cannot be flashed to run a turbine. Therefore, the use of secondary fluids has created interest as a viable alternative to flashing steam. The hot water passes through a heat exchanger and transfers its heat to a liquid such as Freon, Isobutane, Isopentane, etc., which in turn runs the power plant. Figure XI-E-18 is a powerplant which runs on a hot-water-secondary fluid cycle. It is predicted that a minimal amount of technology advancement is needed to make this resource a viable electrical production system.

In exploring geothermal resources the evidence has shown the world to possess numerous hot spots without the availability of natural steam and/or hot water. In fact, it is estimated that between 50 and 90 percent of the energy source of the geothermal reservoir is in hot rock of the earth and not in water and steam.

Hot dry rocks which are impermeable are a source of geothermal energy with heat great enough to generate electricity. The mere drilling of a well is not sufficient to gather the necessary heat in the quantities needed for electricity production. The reason: the low conductivity of rock does not allow the heat transfer to the surface to be as rapid as necessary. The answer is to effect a larger surface area of rock exposed and to pump water into the well to "capture" this heat.

There are presently two general concepts for creating reservoirs in the hot rock. First, cavities can be blown out with either conventional or nuclear explosives. Water would then be pumped into the cavity, circulated and withdrawn to run a power plant similar to those discussed above.

HOT WATER SYSTEM SCHEMATIC

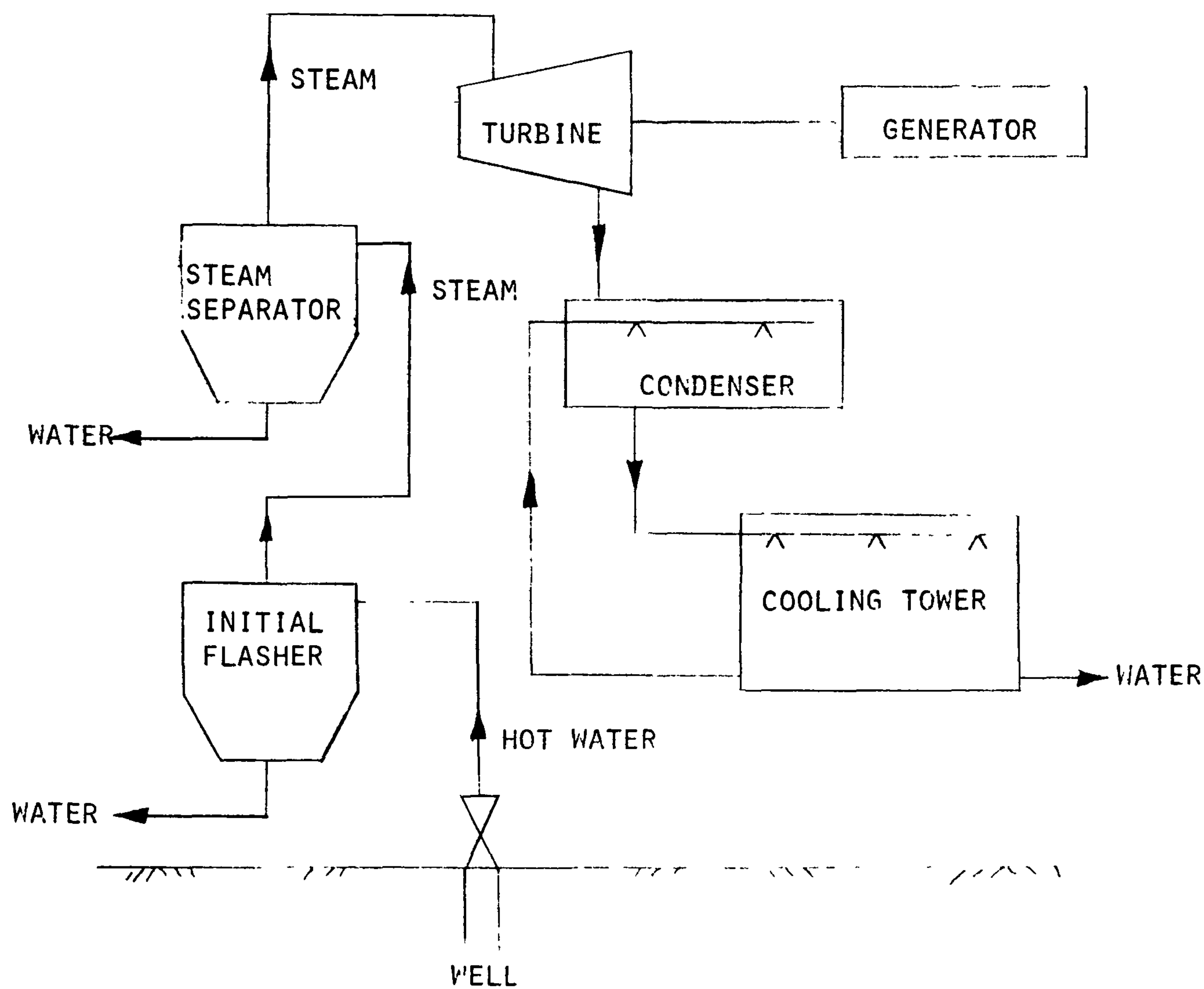


Figure XI-E-17

HOT WATER/SECONDARY FLUID SYSTEM SCHEMATIC

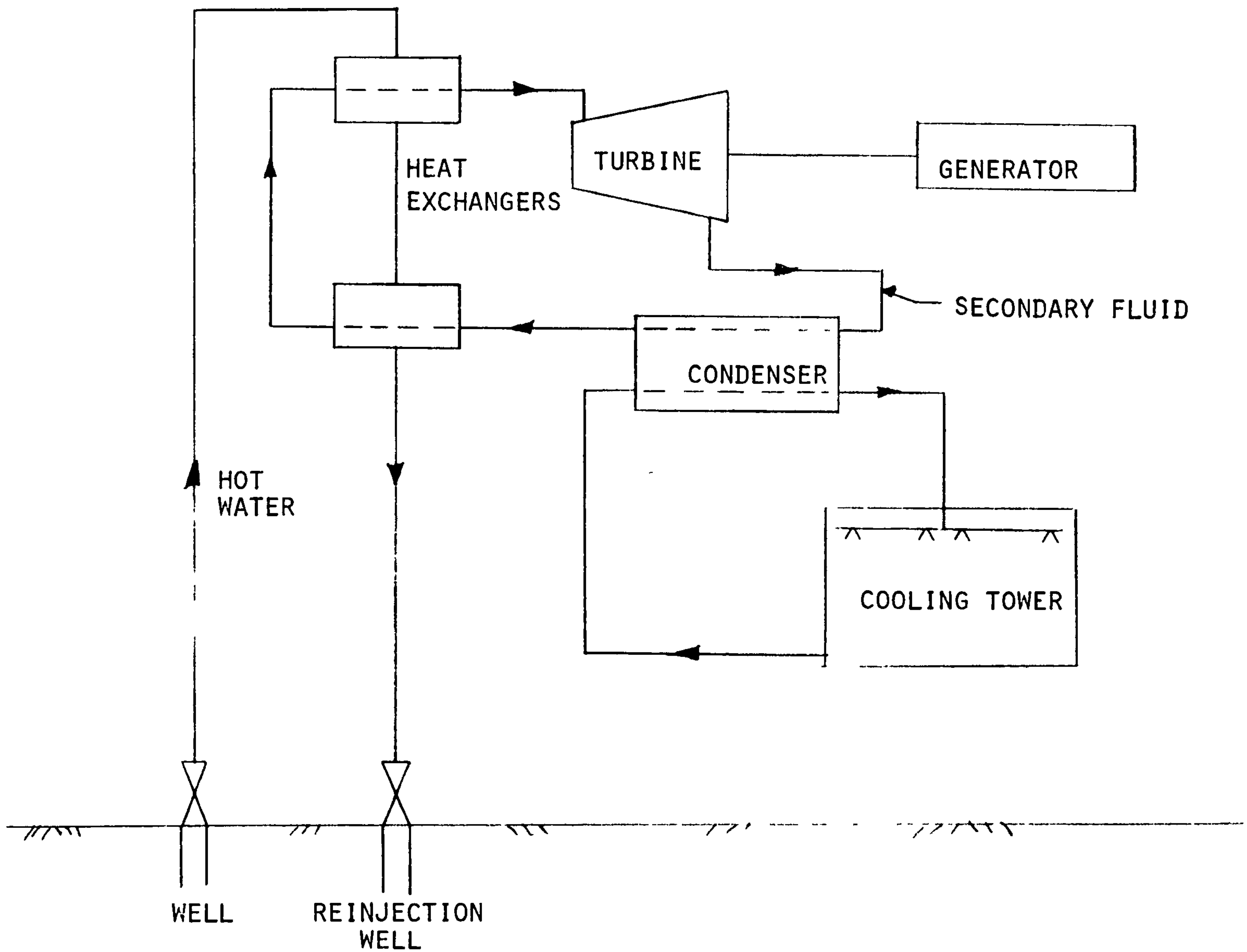


Figure XI-E-18

Quantities of heat gathered in this manner are questioned as to being sufficient to warrant their economic feasibility. Another problem associated with this method is the uncertainty of the underground blasts and their affect on geology of the country. Seismic waves can and do cause shifting of geological formation effecting earth tremors and other activity.

Second, the generally accepted proposal in which there has been much interest is the idea of creating an underground reservoir by producing a crack system and circulating water through the cracks causing it to come in contact with a larger surface area of hot rock. Theories for crack creation have included explosives. However, experimentation is being conducted with a method called hydrofracturing. This is a method of cracking hard rocks such as granite through the use of high pressure water. Figure XI-E-19 depicts a power plant which utilizes a crack system in the hot rock with water circulated so that heat is brought to the surface to use in power production.

At the present time, the total installed generating capacity of the world utilizing geothermal energy is less than 1000 MW_e. About 200 MW_e of the total is in the United States. However, estimates of the geothermal resources of the U. S. vary widely. One estimate predicts that, using present economics and technology, resources are available to support 5000 to 10,000 MW_e installed capacity for 50 years. Another estimate states that, with increased power costs and successful development and application of technology for recovering thermal energy, steam and hot water resources are available to support 13,000,000 MW_e installed capacity and hot rock resources could support another 60,000,000 MW_e installed capacity within the U. S. An estimate of a reasonable contribution of geothermal energy to national electrical power generation is: 1.) 1 to 2% of the national total of 1,000,000 MW_e installed capacity by 1985; 2.) 25% of the 480,000 MW_e installed capacity for the western part of the U. S. by 2000; and 3.) 12.5% of the national total of 2,000,000 MW_e installed capacity by 2000. Table XI-E-4 summarizes the present technology status of geothermal resources power production systems.

Some problems exist with development of the geothermal resource which will be solved as the technology advances and the economics improve. Environmental problems are generally less severe than fossil fuel and nuclear powered power production facilities but include areas such as gaseous pollutants, volatile substances, thermal pollution, high water volume, dissolved minerals, and acoustic pollution. Other problems area to be solved include resource location and evaluation (similar to oil and natural gas but less well understood), drilling technology (high temperature, hot fluids, incompetent formations, large flows of corrosive fluids), corrosion/scaling/plugging, and unknown affects on geology by creating hot rock reservoirs.

Cost projections for geothermal energy electric power generation are not based on a large data base but are very competitive with other conventional power generation costs. Based on cost data from "The Geysers" in California, the cost, in 1975 dollars, for power production facilities capital

CONCEPT OF HOT WATER SYSTEM
USING HOT ROCK RESOURCE

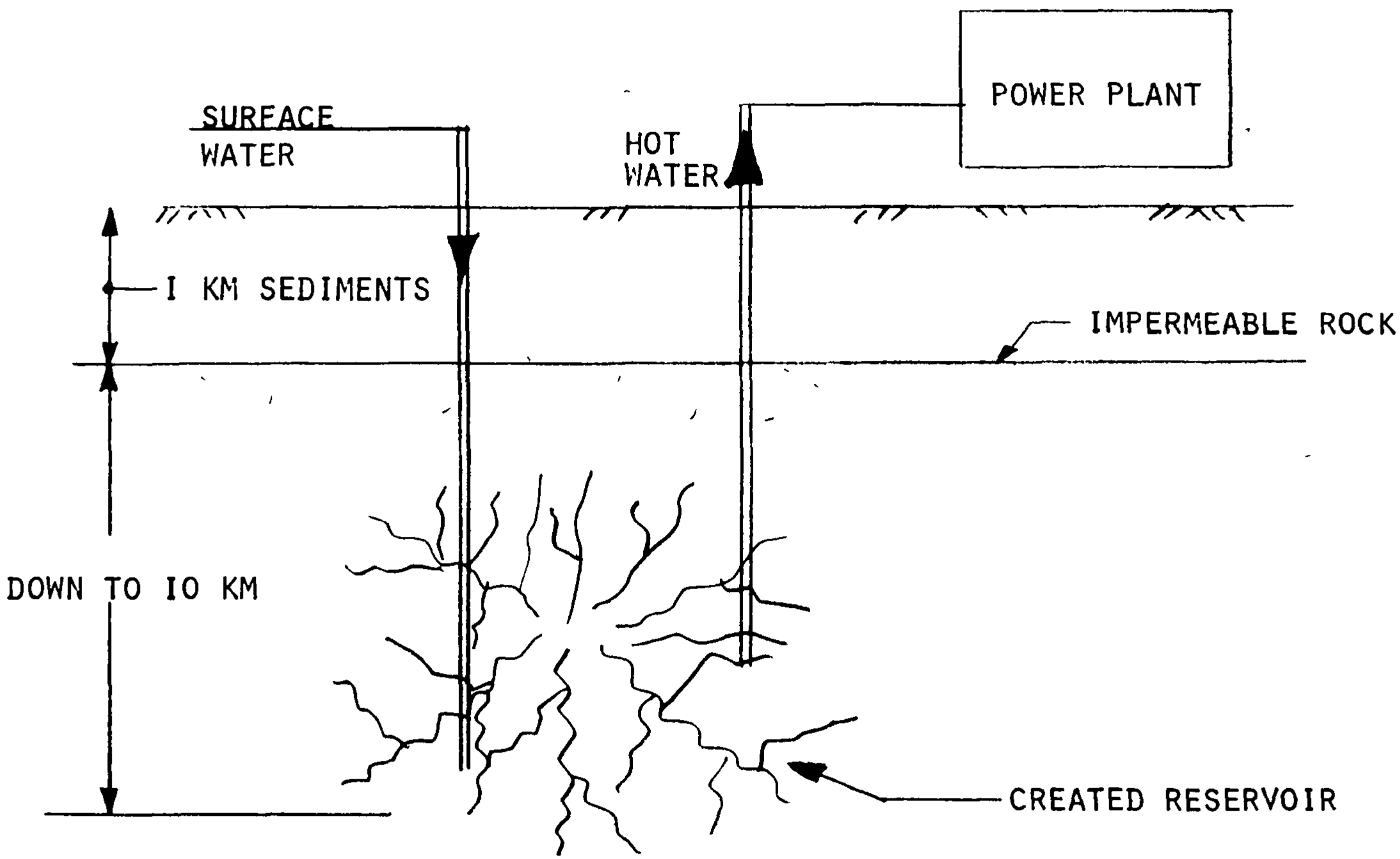


Figure XI-E-19

GEOTHERMAL ENERGY TECHNOLOGY SUMMARY

TECHNOLOGY STATUS	STEAM	HOT WATER	HOT ROCK
o UNITED STATES			
o PRESENT INSTALLATIONS	X		
o RESOURCE INVESTIGATIONS	X	X	X
o OTHER COUNTRIES			
o PRESENT INSTALLATIONS	X	X	
o RESOURCE INVESTIGATIONS	X	X	X

TABLE XI-E-4

investment is $162/KW. The operating cost is 0.37 Mills/KWH and the total cost for power is 7 Mills/KWH. Other projections, for all types of geothermal resource utilization, indicate a total cost of approximately 20 Mills/KWH.

e. <u>OCEAN THERMAL ENERGY CONVERSION (OTEC)</u>: Using the solar energy collected by the world's oceans has attracted interest since the late nineteenth century. In 1881, a publication suggested the possibility of constructing a steam power generator that made use of the temperature difference between the surface water and the deep water in tropical seas. A prototype ocean power plant, based on an "open-cycle" in which the sea water itself provided the working fluid for the turbines, was actually operated in the late 1920's. This plant was not a commercial success because of equipment failures and technical difficulties. However, greater interest has been generated recently because it is believed that the equipment and technical problems will be solved by modern technology, and escalating costs of conventional power generation are making the OTEC plant look more economically advantageous. There are two distinct OTEC plant types with respect to site selections: the shore-based system and the ocean-based system. Either system can be an "open-cycle" (uses sea water as the working fluid) or a "closed-cycle" (uses a secondary fluid such as ammonia as the working fluid) concept. The "closed-cycle" ocean-based concept has received more attention recently because of the versatility of location. A shore-based system would be limited because of availability of sufficient near-tropical land areas to install the number of plants needed to significantly affect the country's electrical energy needs. Therefore, the following description and discussion will deal with only the "closed-cycle" ocean-based concept. A 9-month study of the practicality of this type of plant was conducted by the Lockheed Missiles and Space Company, Inc., for the National Science Foundation Research Applied to National Needs (RANN) program. The Lockheed baseline design concept (figure XI-E-20) consists of a stable, semisubmerged, spar-type platform that can be sited either in the deep ocean or in coastal waters such as the gulf stream. The concept would utilize a mooring system capable of use in water depths of 2500 to 20,000 feet and would consist of a series of pin-connected pipe lengths, designed for minimal current drag, and a single gravity anchor point. The concept employs a central platform through which the water (both warm and cold) is delivered to four removable 60-MW (gross) power plant modules. Each of these four power modules is a completely independent, self-contained power plant consisting of evaporating and condensing heat exchnagers, turbines, generators, condensate pumps, and pumps to circulate warm and cold sea water. The design is such that the power modules can be removed for maintenance and/or periodic replacement. A cold-water pipe extends downward from the central platform to the 1500-ft. water depth. The mean temperature differential between the surface water and the water at the 1500-ft. depth is 34°F. This is the temperature differential which sized the equipment in the Lockheed baseline design concept.

Environmentally speaking, this type plant cannot be compared to fossil-fuel, nuclear, and geothermal systems; because, it does not add heat

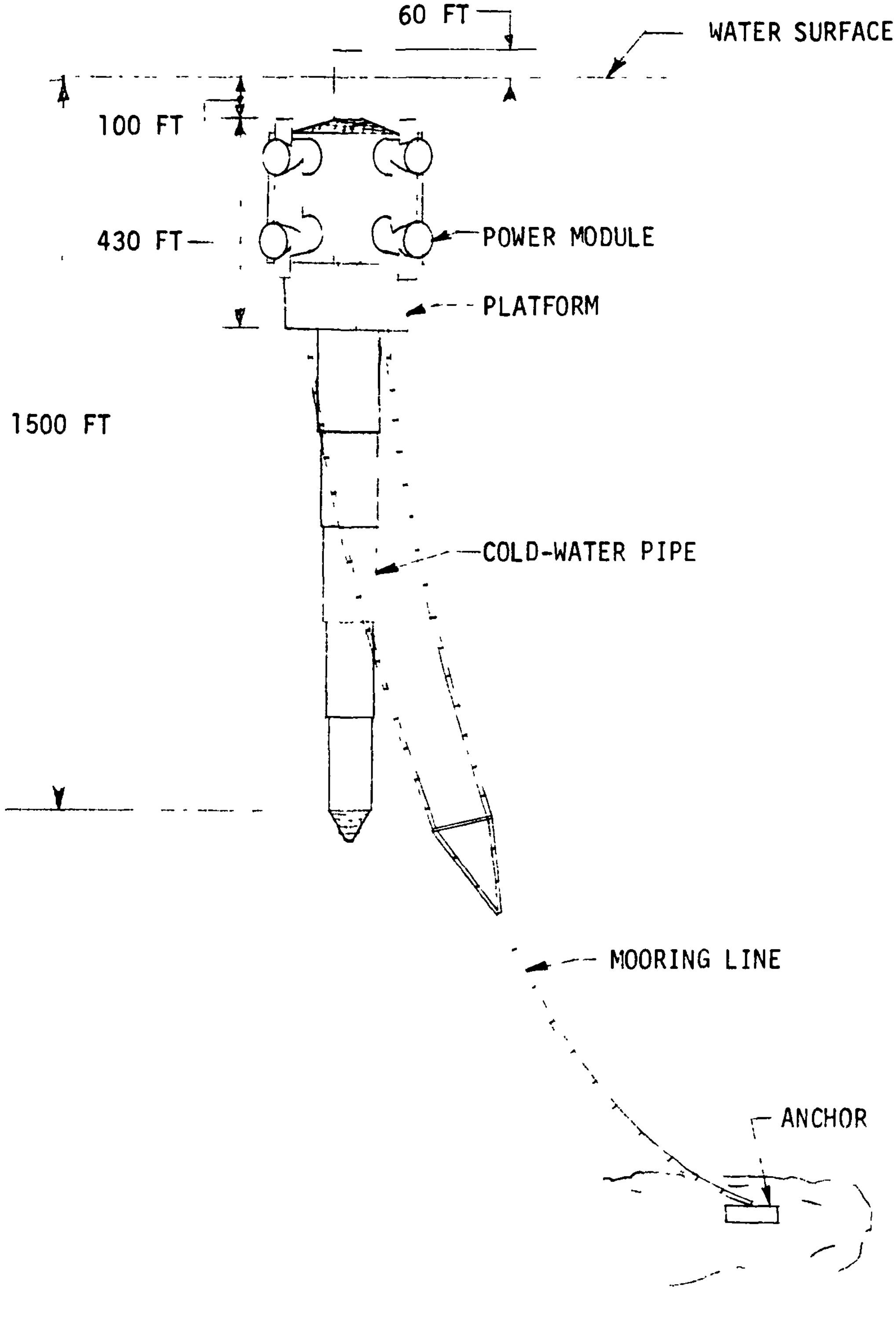


FIGURE XI-E-20: OCEAN THERMAL ENERGY CONVERSION CONCEPTUAL PLANT

to the ecosphere, its waste product is simply the discharge of unpolluted sea water at near-ambient temperature and isothermal depths, and the materials used are compatible with the ocean environment. The only possible hazards that have been identified are the possibility of developing a leak in the ammonia working fluid system and the danger of collision of ships with the platform. A leak detection system for the ammonia system has been designed into the Lockheed baseline; however, ammonia mixing with the sea water would not be detrimental because it will be biologically assimilated. The collision danger is always a problem with shipping. The baseline platform has been designed to be submerged to a depth which will clear all foreseen ships with only a non-critical section extending above water for servicing and personnel entry.

The net power output of a plant like the baseline design is 187 MW's. The production cost of the plant is estimated to be $1,350/KW and the unit cost will be 34.0 Mills/KWH. With improvements in technology in the areas of heat exchangers and sea water pumping, the expected unit cost for multiple units will be 23 Mills/KWH. This value is equivalent to power production with oil, at a 10% cost of capital, of $8.00/barrel.

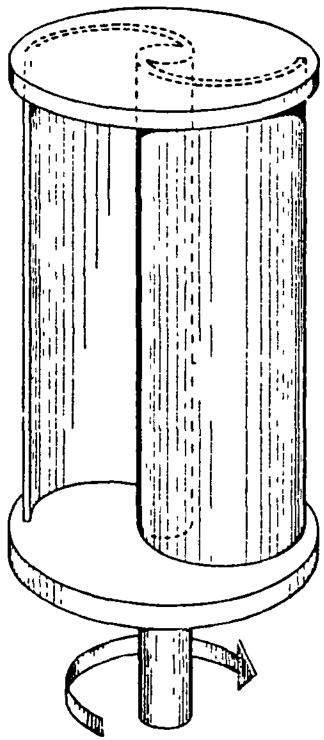
The principal attraction to this method of using solar energy is that there exists a renewable "free fuel" (the ocean is a vast natural collection and storage system) which is available with minimal regard to seasonal and diurnal cycles or weather conditions.

The disadvantages of this type of system are: siting significant numbers of the plants reasonably close to land areas, transmission of the generated power, energy conversion efficiencies of approximately 4%, and large water volume movement.

Current plants within ERDA call for a prototype plant construction in the early 1980's.

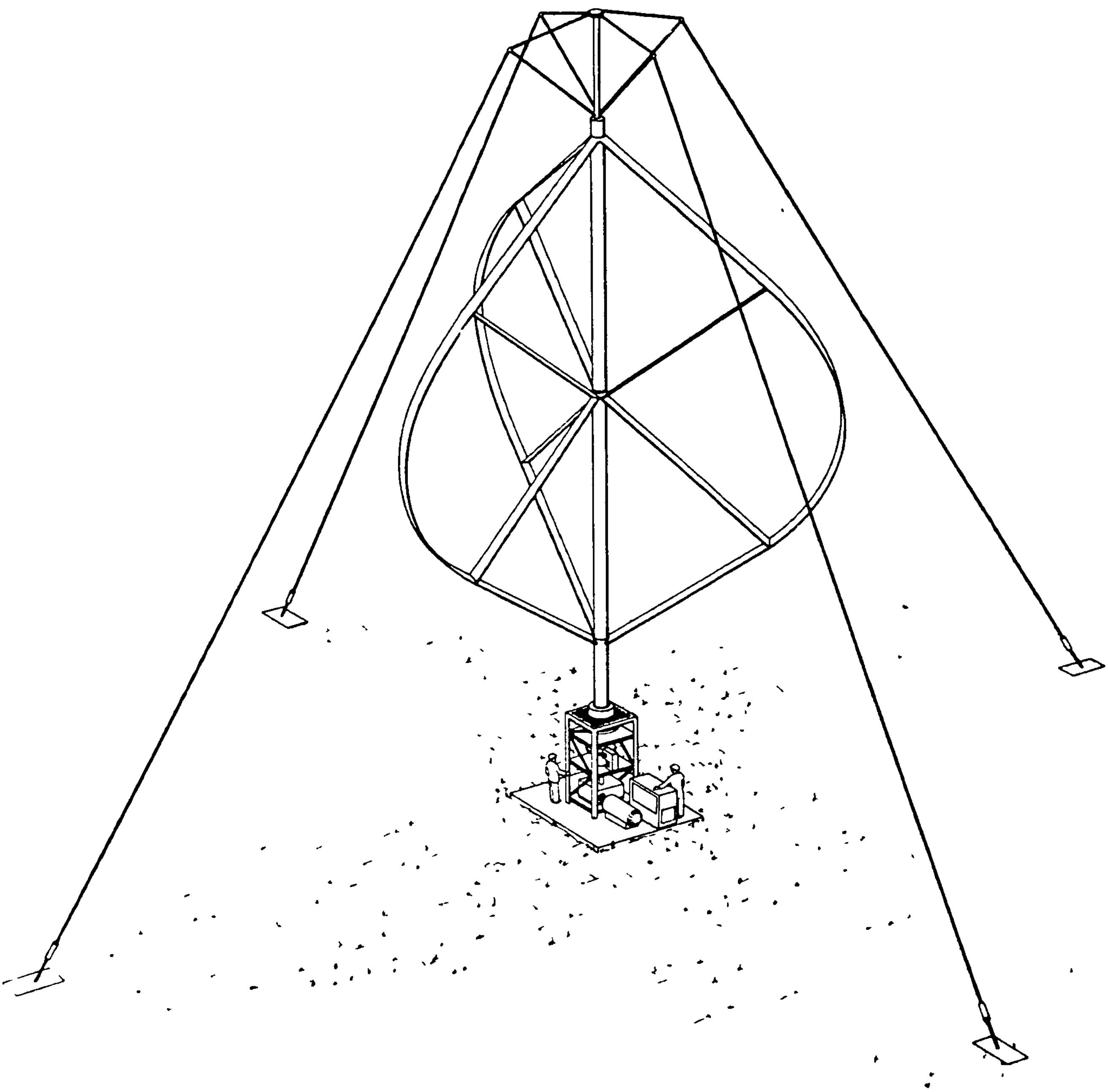
f. WIND ENERGY: Wind energy conversion systems (WECS) generally fall into two categories, vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT). The fairly common sights of horizontal axis systems on farms in the country are taken for granted as they pump water for livestock or generate small amounts of electricity in remote regions. An even more common sight, especially in earlier years in Scandanavian countries, were the centuries-old windmills used primarily to pump seawater from lowlands. As a result, the HAWT is further advanced and currently receives a major portion of the WECS budget for possible large-scale electrical energy production. Several advantages unique to VAWT (i.e. non-directional, vertical axis allows power generation equipment at ground level) however, encourages continued development of these systems. The major emphasis on VAWT is being performed by Sandia Laboratories and is centered on Savonius-type rotors, figure XI-E-21 and Darrieus-type rotors, figure XI-E-22.

Utilization Forecasts: Work on VAWT has progressed as far as current construction of a 17 meter, three-bladed Darrieus rotor and turbine



Savonius Rotor

Figure XI-E-21



Three-blade Darrieus Rotor & Turbine

Figure XI-E-22

test model by Sandia Laboratories and Kaman Aerospace Corporation. Utilization forecasts, obviously, would be extremely premature on all VAWT systems until more experience is gained from the current program.

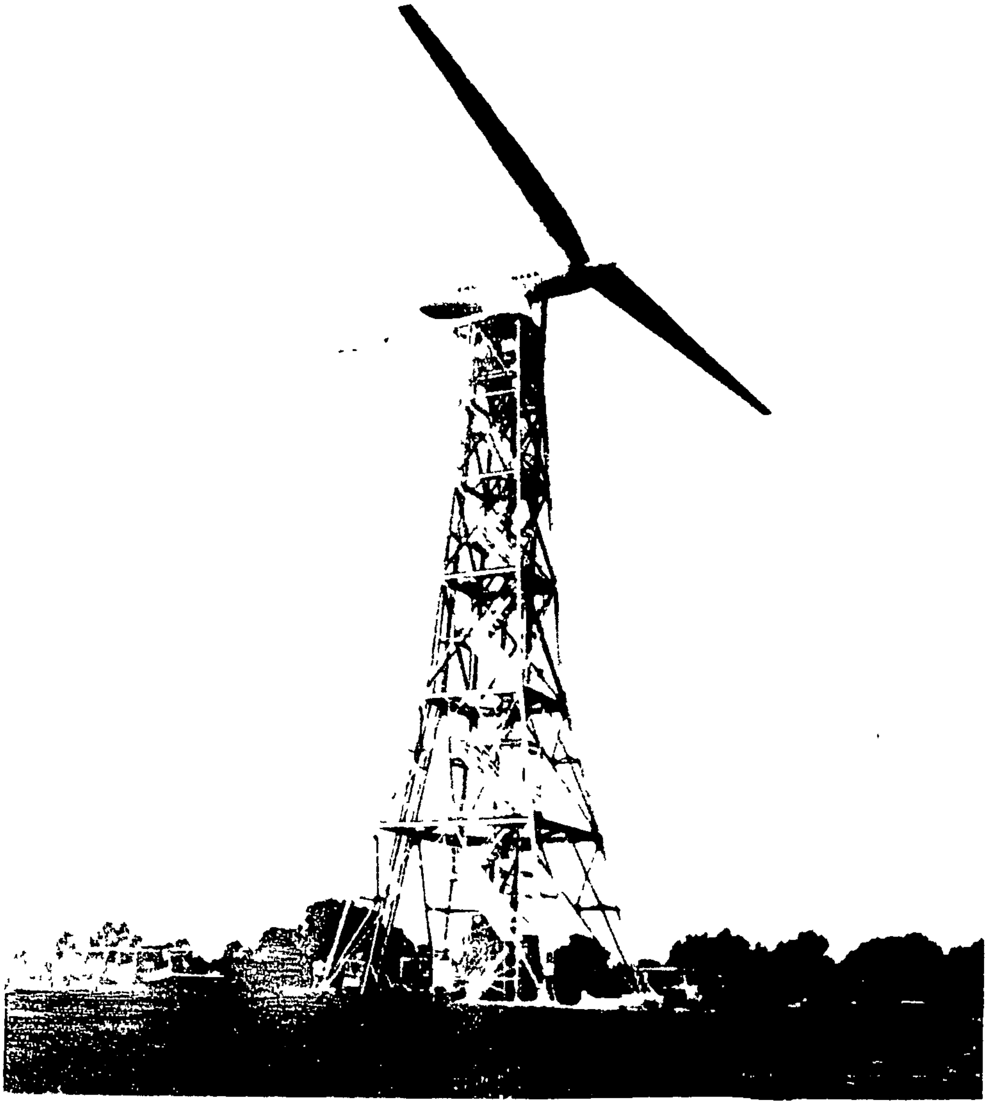
The HAWT program headed by NASA Lewis Research Center (with major contracts to Kaman Aerospace Corporation and General Electric) is much more projectable. A series of demonstration projects have been initiated with the completion of a 125 foot diameter, 100 KW generator system (figure XI-E-23) in 1975. Two additional units capable of 200 KW each are projected for 1977. In 1978, a 200 foot diameter, 1500 KW is planned as the first cost competitive project followed by a 300 foot diameter, 1000 KW unit for low average velocity wind regions. The plan emphasizes grid interface problems as well as technical performance optimization. Concurrently, some site selection activity is underway although remote area meterological data is lacking. Most available wind data must be extrapolated from low level (30 feet above ground level has been the general weather station height) to more suitable heights and out of the effect of ground disturbances (figure XI-E-24).

Since the power output of HAWT systems is proportional not only to the square of the blade diameter, but also to the cube of the wind velocity, accurate assessment of the velocity profiles is essential. Therefore, good estimates in the extensiveness, availability, and accessibility of desirable WECS sites are dependent on a comprehensive survey. This coupled with operational data expected in the next few years will allow very accurate utilization forecasts.

<u>Technology Development</u>: Indicated earlier is the chronological development of HAWT to an expected competitive level. Performance results of the initial unit, (125'O, 100KW) are expected in 1977. Major technical problems uncovered in initial testing include the larger than expected blade bending moments caused by tower blockage, exceedingly high labor costs associated with acceptable tower construction and fabrication problems concerning large rotor blades.

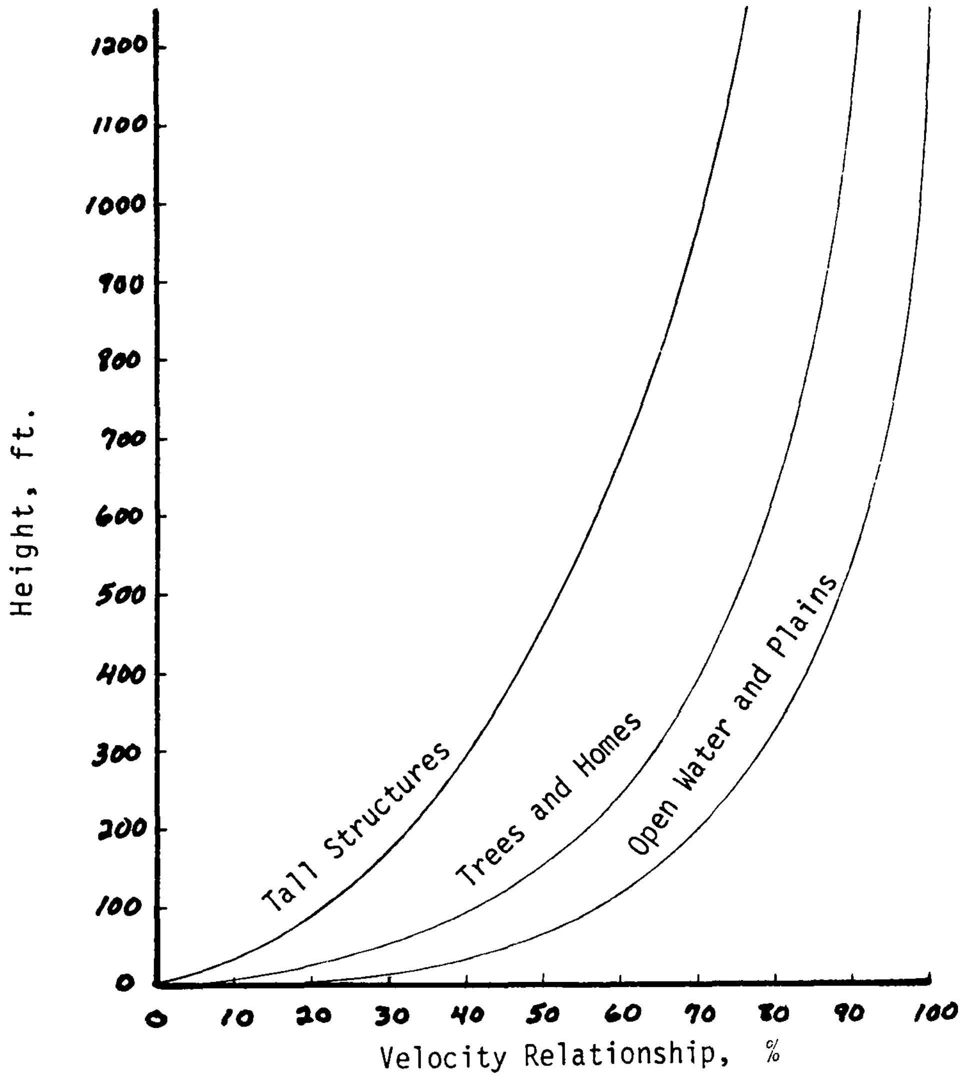
<u>Environmental Considerations</u>: The impact of large WECS dotting the countryside is being considered in the on-going LeRC programs. Not only are the effects of the rotor in downstream winds being determined to establish spacing on "WECS farms," but also aesthetics, the effects on local television reception, the impact of blade noise levels, and the addition of numerous aircraft hazards are part of the studies.

<u>Cost Projections</u>: Initial cost estimates by Kaman and General Electric in independent parametric studies showed a large dispersion in results. The differences were sufficiently resolved so that figure XI-E-25 was presented in preliminary reports as a basis for cost estimates. Using this cost data and other assumptions listed in table XI-E-5, an annual energy cost of 32.8 mils/kwh for 1975 was established. This is high by current energy costs, but apparently competitive in the near future.



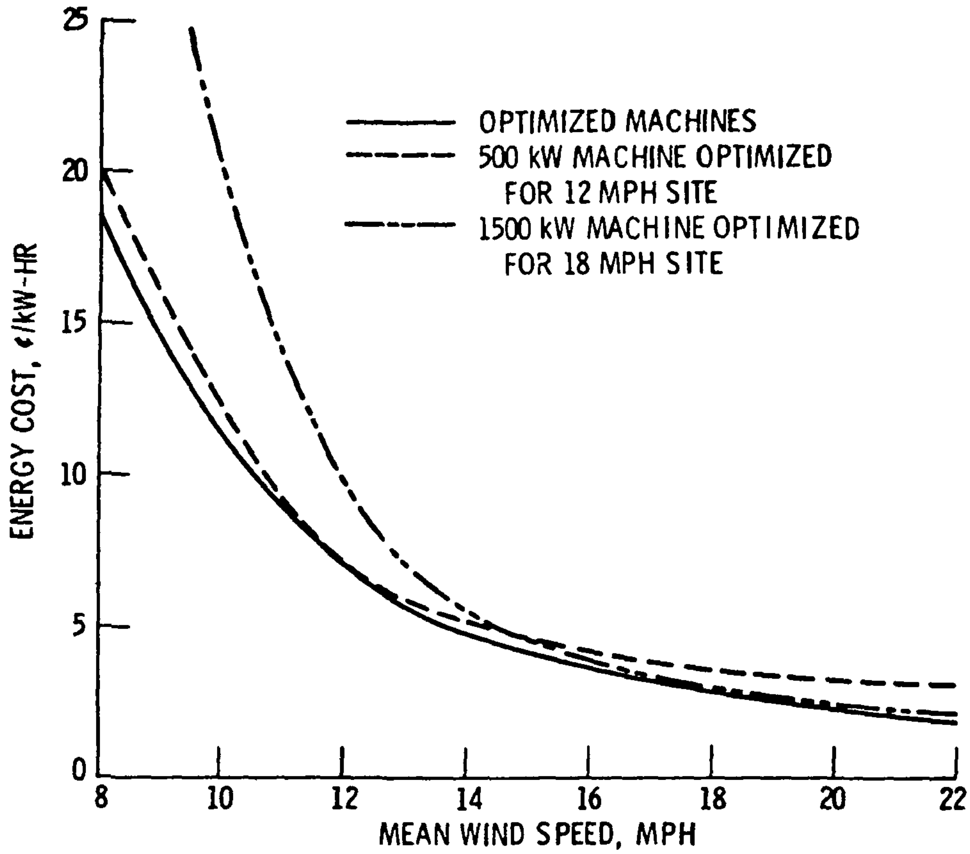
100 KW WIND TURBINE

Figure XI-E-23



EFFECT OF TERRAIN ON WIND VELOCITY

Figure XI-E-24



Effect of siting-12 and 18 mph optimized machines located in various wind regimes.

Figure XI-E-25

RESULTS OF EXAMPLE WECS PROBLEM

- ASSUMPTIONS
  - 1500 KW WECS OPTIMIZED FOR $\overline{18}$ MPH SITE
  - LeRC ENERGY COST ESTIMATES FOR 1975
  - ADJUSTMENT OF 30' MEASURED WIND DATA TO 150' HUB HEIGHT
  - 18 MPH SITE @ 150' CORRECTS TO $\overline{11.7}$ MPH SITE @ 30'
  - HOUSTON = $\overline{11.8}$ MPH SITE ∴ USE HOUSTON FREQUENCY PROFILE

- PERFORMANCE RESULTS
  - PLANT FACTOR = 0.76
  - ANNUAL ENERGY COST = 32.8 MILS/KWH
  - ANNUAL ENERGY PROVIDED 10 GWH
  - 2200 SIMILAR INSTALLATIONS COULD HAVE PROVIDED 1% OF NATION'S ELECTRICAL ENERGY PRODUCTION IN 1975

Table XI-E-5

g. OIL SHALE: Oil shale has long been known as a potential source of energy. A U. S. oil shale industry would probably have developed in the late 1800's and early 1900's had it not been for the discovery of large oil fields in Texas and elsewhere. The problem in the U. S. has been one of economics rather than purely technological. In some countries where crude oil has been scarce and expensive for years, oil shale has been commercially mineral and processed into liquid fuels.

According to reference 2, the first commercial processing occurred in France in 1838; production continued there and in Scotland and South Africa until the early 1960's. Currently, oil shale is commercially processed in China, Sweden, and Spain; raw oil shale is being burned to fire electrical power plants in Estonia and the Federal Republic of Germany.

As the demand for liquid fuels increase and with interest in becoming domestically self-sufficient, it is expected that oil shale development will receive increased support.

Figure XI-E-26 shows the locations of the major oil shale deposits in the U. S. It is estimated that 90 percent of the identified resources are located in the Green River formation in Colorado, Utah, and Wyoming.

A detail discussion of the technology, environmental considerations, economics, and utilization projection of oil shale is beyond the scope of this report. However, with respect to projections, it is estimated that the total U. S. oil shale identified resources is about 1000 billions of barrels of oil.* On an energy basis, this exceeds the identified coal resources and therefore, a very significant domestic energy resource.

Projections: It is generally believed that oil shale development will continue to be pursued. However, to become a major energy source, numerous large scale processing plants must be developed and put into operation. Possible limitations are: lack of large water supply at the ore locations; and environmental consideration of large quantities of residual materials from the processing plants. Nevertheless, it is expected that three to six percent of the power generators in 2000 may be oil shale-derived fuel.

h. BIOCONVERSION: One approach to utilization of solar energy is to use the process of bioconversion as a source of fuel. Bioconversion may be used at several levels of sophistication: (1) photochemical reactions, (2) chemical changes to produce fuel, and (3) use plant material as fuel.

The highest level of sophistication is the photochemical reactions which are often aided by catalysts and used for the direct production of a fuel. Some investigators are searching for ways to accomplish the production of hydrogen by this process.

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*1974 World Energy Conference (PIC report)

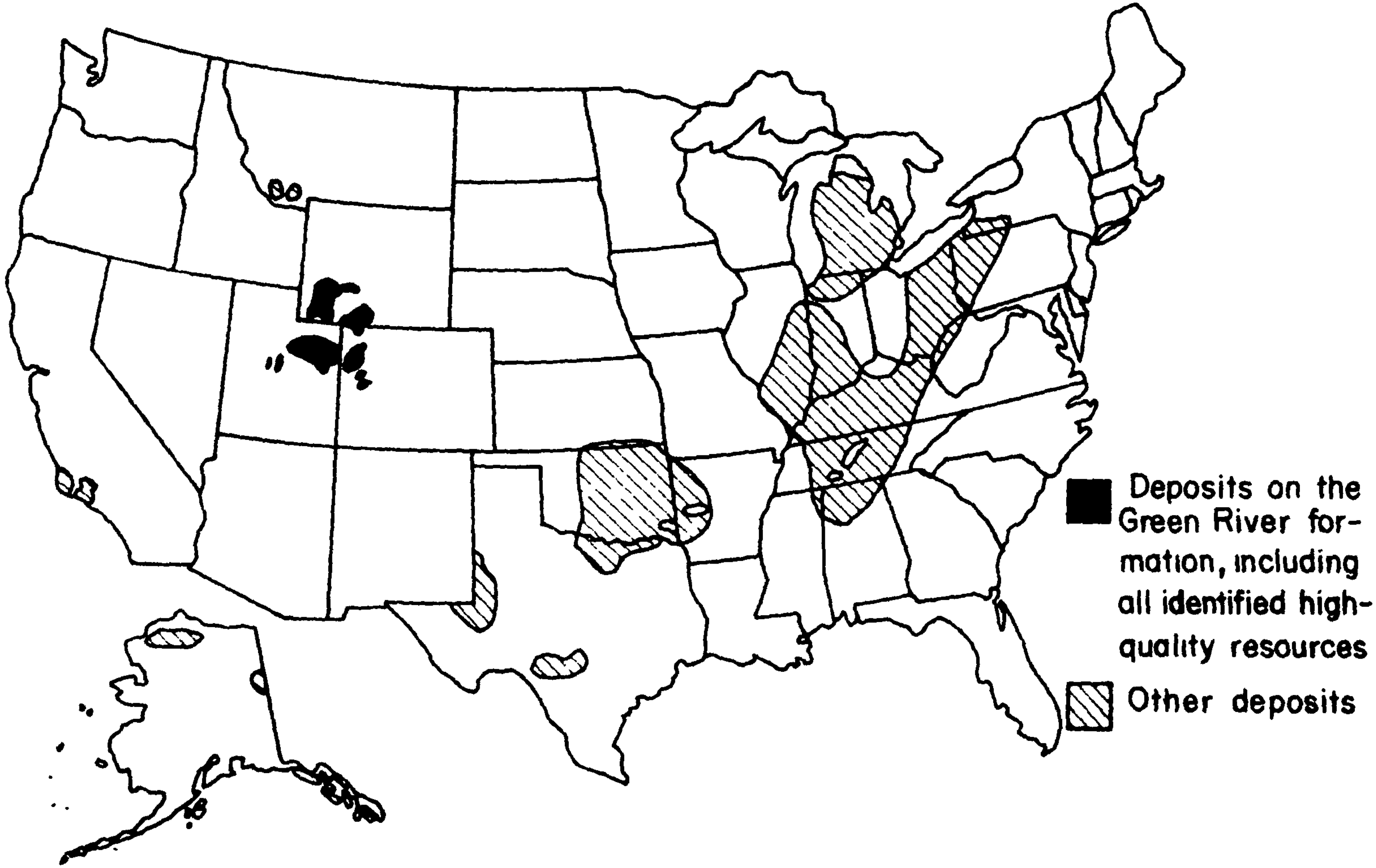

Figure XI-E-26 Distribution of U.S. Oil Shale Resources

Source: Duncan and Swanson, 1965.

In the next level, organic materials, either freshly grown or waste products, are changed chemically to produce liquid or gaseous fuels. At present, the best processes for producing these chemical changes are:

(1.) Pyrolysis - High temperatures are used in the absence of oxygen to break the chemical bonds of organic materials and release methane, hydrogen, and various liquids.

(2.) Anaerobic Digestion - The use of bacteria in the absence of oxygen to break down the carbohydrates from plant and animal materials to yield methane, carbon dioxide, and other gases.

(3.) Fermentation - The enzymatic decomposition of sugar molecules into alcohol.

These processes have been designed into pilot plants in several areas of the country primarily for the reduction of waste products. In 1971, the estimated amount of dry, ash-free organic solid wastes produced in the United States which could be considered collectable was 136 million tons. This is about 15.5 per cent of the total generated. This amounts to a net oil potential of 170 million barrels. An example of the costs for these processes is the present cost of producing methane by anaerobic digestion which is approximately $4.00/MBTU. It is forecast that this cost can be reduced to $1.00/MBTU. However, the technologies must be improved to solve present problems to meet this forecast.

The simplest concept is to grow plant materials, dry them and use them for fuel. This concept employs what is called "Energy Plantations" which are areas planted in crops specifically optimized for yield of plant material. It is believed that Energy Plantations are feasible anywhere in the United States where precipitation is 20 inches or more per year, the soil is a few feet deep and the terrain is not too steep for field machinery. Some areas would be conducive to annual crops such as varieties of sugar-cane, sorghum, and prairie grasses. In other areas of the country, various tree species such as hybrid poplar and red alder could be grown in dense plantings on short harvest cycles. Sustained annual yields from these plantations would be between 5 and 15 tons of dry plant material per acre per year. On this basis, the crop from one square mile will be adequate to support the fuel requirements of between one and three megawatts of electric generating capacity at the average thermal efficiency and load factor of public utility thermal electric generating stations in the United States. The cost of the solid fuel produced, chipped or chopped, and loaded for transportation out of the plantation, including profit and costs associated with owning the plantation land, will be between about 90 cents and $1.30 per million BTU. In order to minimize the freight cost of the fuel and the freight cost of returning the ash to the plantation as fertilizer for growing subsequent crops, it would be advantageous to have the power station centrally located in the plantation. It is believed that the Energy Plantation concept will not require land suitable for dirt farming or tree farming

because of the ground requirements postulated.

Considering the state-of-the-art and assuming the required incentives, a realistic assessment of the U. S. energy potential from bioconversion is approximately 3 per cent of the total U. S. energy demand.

The bioconversion processes are still in early stages of development and require considerable research and development to realize their potential for producing usable fuel supplies.

XI. COMPARISONS WITH ALTERNATE SYSTEMS

F. COMPARATIVE ANALYSIS

The previous sections of this report have provided discussions of the various conventional and advanced technology power systems and their projected future utilization. This section provides a synthesis of the descriptive and characteristic information on each system, including the SPS. The objectives are to provide perspective among the various power system alternatives and to summarize the advantages and limitations of the SPS concept relative to alternative systems.

The approach utilized was to develop comparative data for each system sized at 5 GW plant capacity. This capacity was selected because it is the reference capacity of one SPS rectenna. It was not necessary that unit capacity be 5 GW . . . the 5 GW capacity could be obtained by multiple units of smaller capacity.

It was also assumed that the various power system technologies could be made available by the 1995-2000 time frame. It is realized that there is uncertainty at present regarding the future of fusion power, the liquid metal fast breeder reactor (LMFBR), and oil shale development. For purposes of comparisons, these were assumed to be viable candidates for the future since there is no firm technical basis for excluding them at present.

Bioconversion was excluded from final system comparisons due to lack of data relative to large scale power generation capability.

The comparison factors utilized were technological status, costs, and environmental considerations. Technological considerations included current (1976) status economic size, expected commercial data, key problems, and potential or anticipated electrical energy production in the year 2000. Technology status in 1976 was expressed in terms of proven demonstration in progress, laboratory, or conceptual.

Cost data was determined in terms of capital cost, fuel cost (as applicable), and operation and maintenance costs. This data was summarized in terms of power generation costs (mills/kwh) using 30 year lifetime and 15 percent rate of return on investment in each case. The plant factor used in cost calculations varied from system to system based on their design/operation characteristics.

Environmental comparison data was developed in terms of land use, water consumption (cooling and process), air pollution, waste storage/disposal quantities, and other factors as applicable.

In addition to the above comparisons, more detailed comparisons were made between SPS and terrestrial solar electric power in terms of design concepts, costs, and power transmission considerations. A review and assessment of the material presented in this chapter was made by Stanford University

under contract to JSC. A brief summary of their report is presented in XI-G below.

Technological Status

Table XI-F-1 presents a summary of the technological status of the power system alternatives. Most of the data is self-explanatory except economic size and potential/anticipated contribution in the year 2000. Economic size (expressed in megawatts) is the minimum plant capacity that results in lowest overall power generation cost. This size may be dictated by the largest capacity component (e.g., steam turbine, generator) available or transportable. The value given for SPS (5000 Mw) is based on very preliminary system sizing studies, primarily related to microwave transmission considerations. The potential anticipated contribution column of Table XI-F-1 is the percentage of the year 2000 electrical energy demand (kilowatts) that could be supplied by the given source. The year 2000 demand utilized to determine the percentages was 10 X 10^{12} kwh from the projected Federal Power Commission data previously discussed.

The general conclusion to be drawn from Table XI-F-2 is that no single electrical power source will be utilized to the exclusion of other sources. Coal and nuclear (LWR) energy are proven technologies and they will produce almost 75 percent of the nation's electrical energy in 2000. Another significant point is that less than 5 to 6 percent of the total electrical energy will be generated by renewable energy sources, even after the 23 years of development between now and 2000. The 5 to 6 percent does not include SPS, which could provide another approximately 6 percent in 2000 if implemented per JSC scenario "B" (see section III.)

Cost Comparisons

Figure XI-F-1 shows a summary comparison of the cost of electricity for the various alternatives investigated. The solid line represents the range of actual and estimated costs at the busbar (transmission and distribution costs not included) expressed in 1976 dollars. The actual costs are, of course, associated with the conventional systems (natural gas, oil, coal, nuclear LWR, hydro). In the case of the advanced systems, the costs were derived from available sources that tend to be advocates of the particular technology. Therefore, to some extent the low-end of cost ranges probably reflect considerable optimism with respect to realizable costs.

No attempt was made to "adjust" the figures through critical analysis because of the difficulty in obtaining of the required detailed cost parameters utilized by the individual sources.

The lower horizontal line marked "Year 1976" is the upper limit of the average coal-fired power generation (26 mills/kwh) and it probably represents the upper limit of the 1976 competitive range. The fuel cost portion of the 26 mills/kwh is 11 mills/kwh, which corresponds to $1.10 per million BTU or $22/ton coal. In some parts of the country, coal costs up to $35/ton in large quantities.

TABLE XI-F-1- TECHNOLOGY STATUS AND PROJECTIONS

System	Technological Status, cost ($ x 10^6), fiscal year 1976	Economic size, mw	Expected commercial use	Key problems	Potential/Anticipated contribution, percent (year 2000)
Natural gas	Proven	600	Present	Fuel supply	[a]6 to 7
Oil	Proven	600	Present	Fuel supply	[a]7 to 8
Coal with stack gas cleanup	Research demonstrations $52, FY77	600	1978	Mining, transport stack gas cleanup	25
Oil shale	Pilot plant, $12, FY77	[b]150,000 tons/day	1980 to 1985	Water supply, plant sizing	3 to 6
Fission. LWR	Proven	600	Present	U235 supply, plant sizing	48
Fission: HTGR	Demonstration, $0, FY77	1200	1985	U235 and Th232 supply, limited development	No estimate
Fission: LMFBR	Demonstration, $665	1500	1988 to 1990	Safety design, plant sizing, fuel process, development	[a]10
Fusion	Research, $392, FY77	5000	After 2000	Basic design for net energy production with sustained operation	0
Ground solar	Laboratory to pilot plant,	Unknown	1985 to 1995	Low-cost component energy storage	1
Geothermal	Geyser - proven; $100, FY77	200	Geyser - present;	Drilling, well completion,	2 to 3
Wing (large)	Demonstration, $15, FY77	.5	Early 1980's	Site selection, component cost	2
Hydroelectric	Proven, $0	40	Present	Site location and acquisition	3 to 5
Ocean thermal	Conceptual, $8.2, FY77	160	1985 to 1990	Heat-exchanger fouling, remote location, high capital cost	1
SPS	Conceptual	5000	1995	High costs, transportation, solar conversion, pilot demonstration	6 (Scenario B)

[a]Percentage of electricity.
[b]150,000 tons/day.

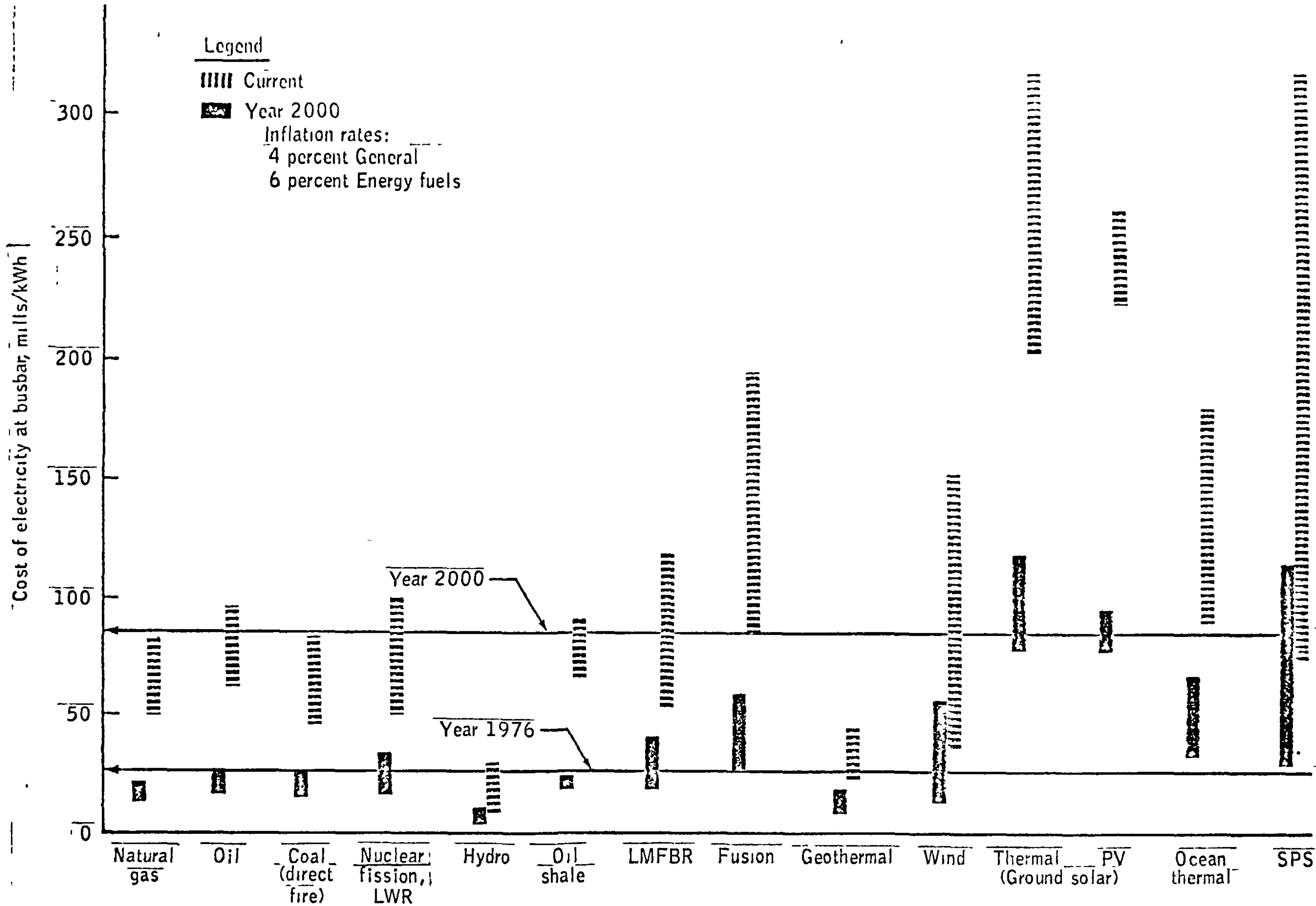

Figure XI-F-1 Power Generation Costs

The dashed vertical bars shown in figure XI-F-1 represent the year 2000 cost of electricity for the various alternatives. The projections were obtained by applying the following inflation factors to the 1976 costs:

General inflation. . . . . .4 percent compounded annually

Fuel cost portion

of fuel-using systems. . . .6 percent compounded annually

With the above inflation applied, the year 2000 upper-limit cost of electricity for coal-fired systems increases to about 82 mills/kwh.

Note that the hydroelectric, wind and geothermal power are very low cost in comparison with the other systems. These systems do not use fuel and, therefore, are not subject to the differential inflation assumed. Also, the geothermal costs are based on optimistic development of geothermal resources. The existing geothermal geyser power plants (northern California) have low power production costs, which probably biase the geothermal cost estimates to the low side. Hydroelectric power is generally low-cost power where available because (a) there is no fuel charge, (b) capital is relatively high, but is written-off over very long plant lifetimes and (c) maintenance costs are relatively low. The wind power estimates are based on operation in the "fuel saver" mode in conjunction with some other type of power plant in order to provide continuous service. No storage is used; therefore, the system is not a baseload plant.

The ground solar electric systems shown are for thermal and photovoltaic conversion concepts derived by JSC for purposes of cost comparison. This was necessary because no complete system cost could be found in the literature. The concepts are, however, based on subsystem technology currently under development. The thermal system utilizes a "power tower" concept with a combination fuel cell-electrolysis cell energy storage system to provide baseload capability. The energy is stored in the form of cryogenic hydrogen (60 hours capacity). The photovoltaic system utilizes the same type of storage system and its capital cost assumes the use of $300 per peak kilowatt solar cells. The plant site location assumed was southwestern United States with an average annual in solution of 2500 kwh/m^2 total (direct and diffuse). The solar thermal concept was based on 2641 kwh/m^2 year direct.

The year 2000 startup SPS cost range, based on the above inflation factor, is 74 to 294 mills/kwh. The lower range is comparable (actually less than) the coal system cost in 2000 and it is competitive with nuclear (LWR and LMFBR). In its higher estimated cost range, SPS is comparable to nuclear fusion, terrestrial solar electric, and ocean thermal.

Figure XI-F-2 is shown to illustrate the effect of fuel cost on cost of electricity for coal, nuclear and oil-fired systems. The cost curves shown do not include inflation. The nominal, maximum, and minimum SPS

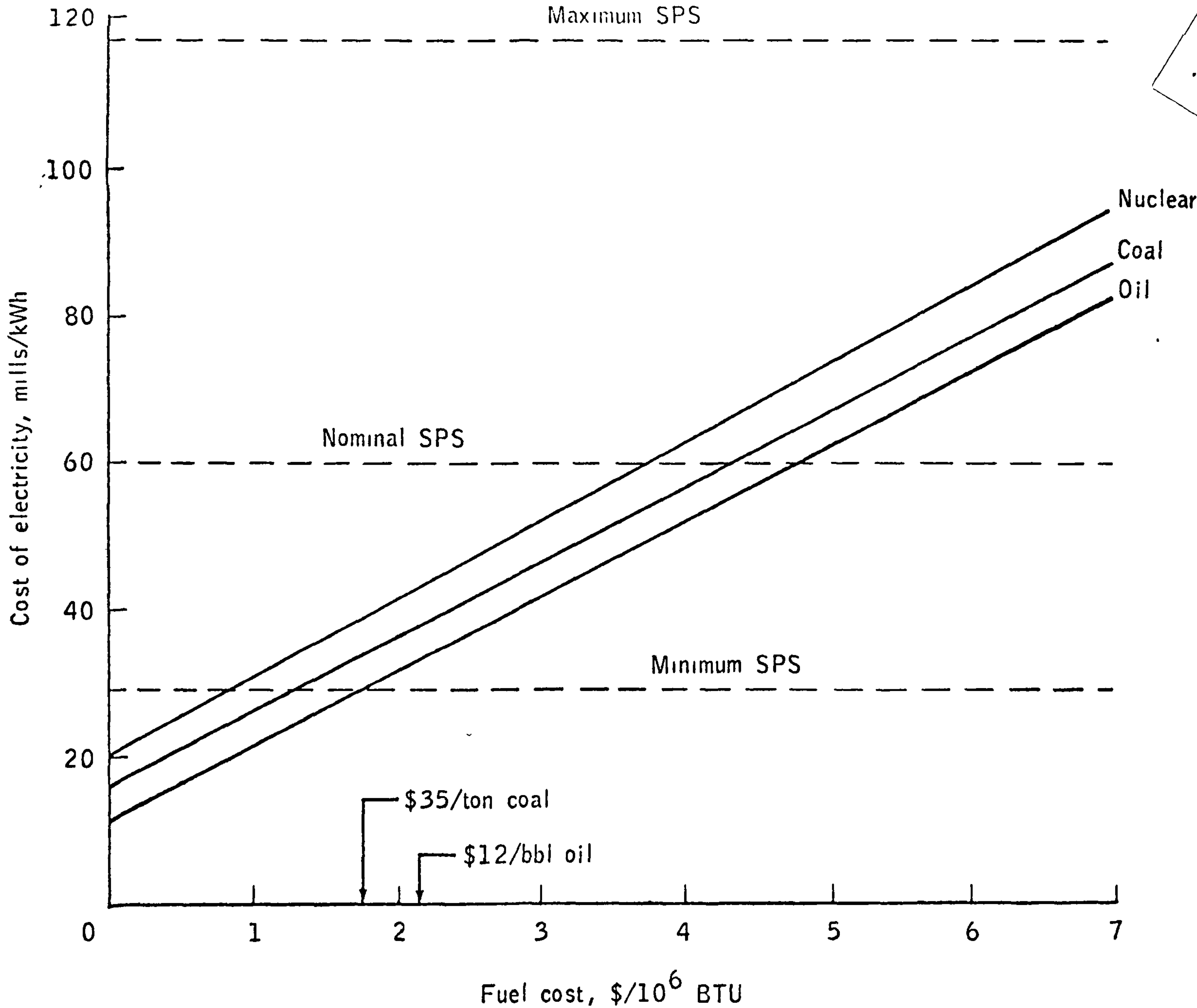
Maximum SPS
Nominal SPS
Minimum SPS
Nuclear
Coal
Oil
$35/ton coal
$12/bbl oil
Cost of electricity, mills/kWh
120
100
80
60
40
20
0
1
2
3
4
5
6
7
Fuel cost, $/10^6 BTU

Figure XI-F-2

generation costs are shown for reference and, as indicated, they would be independent of fuel costs.

Environmental Considerations

Table XI-F-2 shows a comparison of the power system alternatives in terms of the environmental factors of land use, water consumption, air pollution (with abatement), waste storage/disposal requirements, and other factors. The values shown are for a 5000 Mw (5 Gw) power plant capacity. The range of land use for the natural gas, oil, coal, and nuclear systems reflects differences in cooling requirements primarily. The larger land requirement is associated with a system that uses a dedicated cooling pond (or lake) for waste heat rejection. The land use factor includes the steady-state land requirements for surface mining operations, accounting for a 10 year reclamation cycle. The land requirement for wind power is based on an approximation of 40 Mw per square mile in the midwest (ref. 2).

The land requirement for SPS is based on a 10 km times 14 km rectenna for a 5 Gw output. The water consumption values are for cooling and process requirements. The cooling mode assumed was wet cooling towers where the water is actually lost through evaporation and drift. For once through cooling systems, the cooling water flow requirements would be higher then indicated.

The air pollution values shown are for steady-state operation. The one exception is the SPS where the air pollution values shown originate from rocket propulsion through the atmosphere and apply to the satellite construction period only. The nuclear systems have various levels of radioactive substances emitted to the air as indicated in the table in terms of curies (Ci) per year.

Summary Remarks

Based on the preceding data and discussion, several general conclusions may be made relative to SPS as follows.

1. To the depth studied, SPS is potentially cost competitive with alternative sources in the year 2000 time period.

2. Inflation of fuel costs at a higher than general inflation rate improves the competitive position of SPS relative to fuel using systems, i.e., coal, nuclear (LWR), oil/gas.

3. SPS offers environmental advantages of very low air pollution, no major cooling or process water requirements and no significant residual material for storage and/or disposal. Questions regarding microwave effects on the environment require further analysis for resolution.

4. There will continue to be a large mix of power system technologies utilized in the future even though sources such as oil and gas will be curtailed. No single source will dominate the power generation utility field although it appears that about 75 percent of the power will be produced by coal and nuclear energy at the turn of the century.

TABLE XI F-2- 5000-MW PLANT ENVIRONMENTAL FACTORS

System	Land use, km^2	Water consumption, 10^9 gal/yr: Cooling	Water consumption, 10^9 gal/yr: Process	Air pollution with abatement: SO_{x3} 10^3 tons/yr	Air pollution with abatement: NO_{x3} 10^3 tons/yr	Particles 10^3 tons/yr	10^3 Ci/yr	Waste storage/disposal	Other factors
Natural gas	4-31	13	1.5	0.1	55	2.1	0	Small	
Oil	17-43	13	1 5	235	105	8	0	Small	
Coal (direct fire with stack gas cleanup)	21-45	13	1.5	80	100	16	0	2 to $5X10^6$ tons/yr, disposal	Fuel supply by rail undesirable
Oil shale	16-38	13	15-45	0.8	1.2	5	0	$125X10^6$ tons/yr, disposal	85% of ore concentrated in small region
Fission: LWR	5-38	18	1	3.5	4	0.3	7 to 50	Storage 65 000 to 180 000 ft^3/yr	
Fission: LMFBR	5-30	14	1	Small	Small	Small	3 to 7	Storage 80 000 to 210 000 ft^3/yr	
Fusion	( )	13	( )	Small	Small	Small	4 to 40	( )	
Geothermal	110	0-30	( )	(a)	(a)	(a)	0	12 to $200X10^6$ tons/yr, waste water disposal	Land-subsidence questions
Wind	348	0	0	0	0	0	0	0	Unfavorable aesthetics - many towers
Ground solar:									
Thermal	142	13	0	0	0	0	0	0	
Photovoltaic	465	0	0	0	0	0	0	0	
Hydroelectric	574	0	0	0	0	0	0	0	Recreation, flood control, and other benefits
Ocean thermal	Small	0	0	0	0	0	0	0	
Satellite solar	110	0	0	[b]4	[b]2	Small[b]	0	0	

[a] H_2S, 200 000 tons/yr, NH_3, 270 000 tons/yr.
[b] Launch year, only.

G. RELATED CONTRACTUAL STUDY

A brief review of the preceding alternative power system material was made by a team of experts at Stanford University under contract NAS9-15317 with JSC. The objectives (tasks) of the contract were as follows:

1. Review and assess work previously accomplished by JSC, including supporting data, in alternative power systems in relation to SPS concepts.

2. Provide written and oral comments on the results of the review.

The level of effort of this contract was about 8 man days involving four experts during a two-week period in April 1977. The cost of the contractual effort was about $2900 total, including travel costs.

The work performed by the Stanford team was as follows:

1. Participated in an oral presentation by JSC at Stanford on March 24, 1977.

2. Review and assessment of written material.

3. Oral presentation of findings to JSC personnel on April 12, 1977.

4. Preparation and submittal of a written report.

The significant items reported by Stanford were as follows:

1. The electric energy consumption forecast utilized by JSC (Federal Power Commission, 1970) appears too generous in predicting future levels of use. A more conservative projection such as presented in ERDA Reports No. 48 and 49 or Stanford Research Institute "Solar Energy in America's Future" report was suggested for use.

2. A plausible forecast of electricity cost versus time is an essential datum for a comparative study. The JSC study presents the cost estimates for individual sources but not the median price (cost) of a mix of generation sources.

3. The JSC material was somewhat uncritical and tended to accept without reservations the exaggerated optimism of the proponents of certain technologies.

The above Stanford comments are accepted as valid criticisms of the JSC material. Section III of this report provides elaboration on the impact of alternative energy demand scenarios (relates to 1 above). Regarding item 2, projection of the median cost of electricity with a generation mix should be pursued in future JSC studies. However, it should be pointed out that such studies require major assumptions regarding the level of utilization of different regions of the country. Inflation, socio-political, and environmental factors also have an effect on system utilization. These are highly speculative and uncertain considerations.

Item 3 above was addressed in section IV of this report.

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